MASTER OF BUSINESS ADMINISTRATION

Fuel switching

Value creation through shift of technology and energy sources in the Portuguese industry, services, agriculture and fishing sectors

Pedro Daniel Bastos Cruz

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Advisors:

Professor Paulo José Jubilado Soares de Pinho (Universidade Nova de lisboa)

Engº Pedro Neves Ferreira (EDP Energias de Portugal)

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Abstract

Dissertation title: Value creation through shift of technology and energy sources in the Portuguese industry, services, agriculture and fishing sectors

Author: Pedro Cruz

The present Master dissertation is a project whose main objective is to identify value creation opportunities through fuel switching in the Portuguese industry, services, agriculture and fishing sectors. Fuel switching opportunities are characterized by type of fuel transition, type of technology transition, economy subsectors prone to have fuel switching and value created through fuel shift.

Results suggest tomato concentrate, dairy, beer manufacturing and sugar refining subsectors is where prevalence of fuel oil steam boilers is high, for such cases conversion to natural gas steam boilers should result in operations having a ratio of NPV over CAPEX larger than ten and a payback period just under one year.

Results further suggest food, beverages, textile, chemicals and wood subsectors currently operate between ten and twenty cogeneration Diesel engines that can be either modified to operate with natural gas or replaced by new natural gas cogeneration systems. Financial modeling indicates that both options have great value creation potential.

The current analysis aims to be used by natural gas suppliers and energy project promoters to identify new potential deals as well as by heavy energy consumers to mitigate their energy related costs.

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List of acronyms

APA – Agência Portuguesa do Ambiente

CAPEX – Capital expenditure

CHP – Combined Heat and Power

DGEG – Direcção Geral de Energia e Geologia

ETS – Emissions Trading Scheme

HVAC – Heating Ventilation and Air Conditioning

LPG – Liquid Petroleum Gas

MWh – Megawatt hour, energy unit

MWe – Megawatt electric, power unit of electrical system

MWt – Megawatt thermal, power unit of thermal system

SHP – Separated Heat and Power

toe – ton of oil equivalent

Preface

Firstly, I would like to thank my academic advisor Dr. Paulo Pinho. Dr. Pinho's vast experience in energy and finance were vital in both guiding the research and structuring the results.

The following dissertation was a product of the collaboration between EDP Energias de Portugal S.A. and myself. From September 2012 to December 2012 I joined the Energy Planning Department at EDP as an intern. In this context, I committed exclusively to executing the present thesis while at the same time benefitting from the knowledge and guidance of a team of experienced energy analysts. I thank all members of EDP's Energy Planning Department for guiding me throughout the discovery process, in particular Pedro Neves Ferreira (Head of Energy Planning) and Allen Vasconcelos for their very active roles. Following the success of this collaboration, I was invited to extend my work at the Energy Planning Department, where I will give continuity to the study initiated by this thesis through the analysis of electrification potential in the Portuguese industry.

1. Introduction

The present dissertation is intended to be used by natural gas suppliers and promoters of industrial energy installations as a guide to find new clients. This is achieved by identifying which subsectors of the economy have financial incentive to undergo fuel switching, therefore aligning the incentives of energy project promoters and energy suppliers with the incentives of energy consumers. Fuel switching opportunities are characterized by type of fuel transition, type of technology transition, economy subsectors prone to have fuel switching and value created through it. Focus will be set to on large energy consumers in the Portuguese industry, services, agriculture and fishing sectors.

Motivation for this paper rests on the hypotheses that last decade's oil price increases, EU CO_2 emission reduction policies and increased supply of natural gas in Portugal have created abundant fuel switching opportunities between oil derivatives (more expensive and higher CO_2 emissions) and natural gas (less expensive and lower CO_2 emissions).

Conceptually, the project is divided in three parts: identification of fuel switching candidates, characterization of identified candidates and economic validation of switching opportunities. Physically, the text is divided into four main chapters besides the introduction. (i) "Technology overview" provides a brief introduction to the core technologies of identified fuel switching opportunities. This section demonstrates how different energy technologies can substitute each other. (ii) The chapter "Method" guides the reader through the discovery process used to reach results. It starts with the description of the data sources used, followed by a portrayal of the process employed to identify and characterize industry segments that will be targeted for fuel switching. Lastly, it drives the reader through the steps taken to build the economic model developed to validate switching opportunities. (iii) The "Results" section starts with an overview of last decade's Portuguese energy consumption patterns in industry, services, agriculture and fishing sectors. It follows with the analysis and the characterization of pertinent subsectors. To conclude the chapter, results of fuel switching candidates' economic modeling are presented and analyzed; in particular the model is tested with a sensitivity analysis over the core assumptions. (iv) The last chapter, "Conclusions", comments the most relevant discoveries and issues final remarks on fuel switching potential identified.

Major findings of the present work can be summarized as follows. (i) There is fuel switching potential from LPG to natural gas and from fuel oil to natural gas. LPG and fuel oil consumption are estimated to have a market value of 59 million € and 178 million €

respectively. (ii) LPG is essentially consumed in the food, services, and metal machinery sectors. Transition from LPG to natural gas offers no technological challenges and CAPEX is expected to be low compared to cost savings, however fuel switching to natural gas could be limited due to lack of distribution network. (iii) Fuel oil is mainly consumed in boilers in the food and beverages industries or in cogeneration Diesel engines across a variety of sectors, such as services, food, chemicals, textiles and paper. Fuel oil transition to natural gas has been a strong trend in Portugal over the last decade and this tendency is expected to continue. Transition from fuel oil to natural gas is a large positive NPV deal regardless of the technology switch involved.

2. Technology overview

This chapter contains a brief overview of the technology relevant to the data analysis present in this work project, its objective is to show under what circumstances these technologies can substitute each other in the industrial process. Three technologies are considered, CHP internal combustion engines, CHP turbines and steam boilers. All three technologies have the ability to produce steam, steam because it is easy to transport is a commonly used energy carrier in industry.

2.1 CHP technology

Combined Heat and Power (CHP) technology refers to the technology that simultaneously produces heat and power in one single system, alternatively Separated Heat and Power (SHP) refers to the classic heat or power production. CHP integrates heat and power into one single system increasing fuel efficiency by recovering heat lost during electricity production. It is common for a CHP system to achieve 5% to 15% fuel efficiency vis-à-vis its SHP analog. CHP systems are subsidized by the Portuguese government through the payment of feed in tariffs to the electricity they produce.

2.1.1 Internal combustion engine CHP systems

The internal combustion engine of a CHP plant produces electricity while at the same time heat from exhaust gases are used for industrial processes or ambient heating and cooling. Exhaust gas temperature is usually around 300º to 400º Celsius (DGEG, 2010), gases can be used to produce steam. Capacities typically range between 0.1 and 5 MWe (U.S. Environmental Protection Agency, 2008). There are two main types of internal combustion engines used in CHP, the Diesel engine and the Otto engine. CHP Diesel engines are typically tuned to combust fuel oil while Otto engines may burn natural gas, LPG or biogas.

2.1.2 CHP Gas turbine

In a gas turbine combustion pushes gases through a turbine forcing it to rotate and therefore producing mechanical energy. In a CHP the turbine is coupled to a power generator to produce electricity, during this process the turbine exhausts a significant quantity of hot gases, these gases can be used to produce steam or used directly in industrial processes or ambient heating and cooling. Exhaust gases typically range from 400º to 600º Celsius (DGEG, Universidade de

Coimbra, 2010). Gas turbines are versatile CHP systems, characterized by short start up times and fast load correction. Power capacity can range between 0.1 and 250 MWe (U.S. Environmental Protection Agency, 2008).

2.2 Steam Boiler

The steam boiler is a device used to produce steam, its core principle is that heat produced in a combustion chamber is used produce steam. Steam can then be transported through ducts and deliver heat to the industrial process. A steam boiler may be prepared to burn any common fuel, in Portugal both natural gas and fuel oil are commonly used fuels.

3. Methodology

Methodology consists of four parts. (i) Review of the data sources and data gathering methods. (ii) Characterization of the most relevant fuels used in Portugal followed by the establishment of a metric that helps define fuel switching potential. (iii) Analysis and segmentation of the Portuguese energy balance followed by the identification of the subsectors with higher fuel switching potential. Relevant subsectors are identified using the metric defined in (ii). Finally (iv) guides the reader through the method used to assign economic value to fuel switching candidates.

3.1 Data sources

3.1.1 DGEG – Direcção geral de energia e geologia

Direcção geral de energia e geologia (DGEG) is a Portuguese public institution mandated to evaluate public policy in the areas of energy and geology. To achieve its mandate DGEG releases several energy supply and demand reports and databases, for this thesis three data sources were particularly relevant. (i) Yearly Portuguese energy balances from 2000 to 2011 (DGEG Balanço energético 2000-2011). (ii) Database of the evolution of Portuguese Combined Heat and Power installed capacity [Figure 1]. And (iii) a monthly bulletin of fuel prices in Portugal (DGEG, 2012).

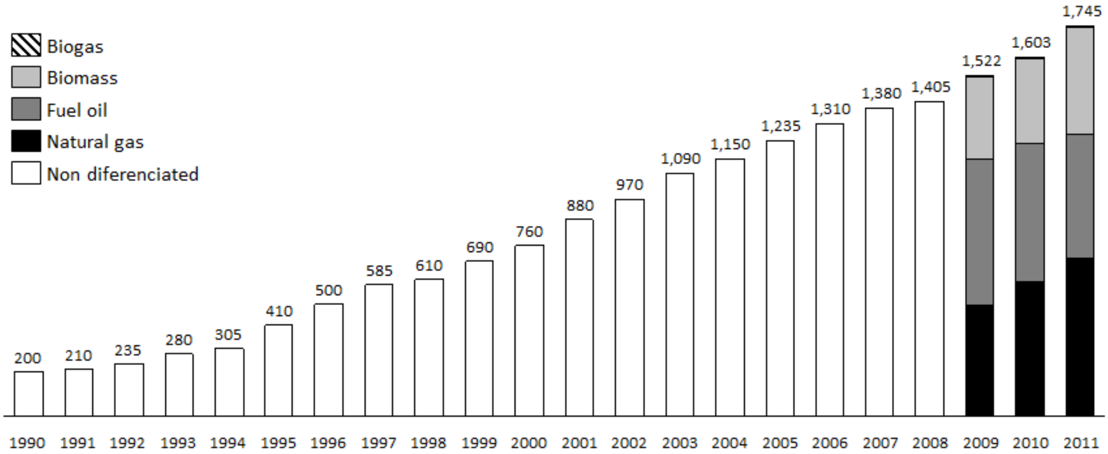


Figure 1 – CHP installed electrical capacity in Portugal (MWe)
Source: DGEG

3.1.2 Eurostat

Eurostat compiles several databases concerning socio economic activity in Europe. During this project three Eurostat databases were used. (i) Eurostat's energy database, used to cross check DGEG information regarding energy consumption and energy prices. (ii) Eurostat's international trade database, used to estimate energy prices of petroleum coke. Finally (iii) the database on the statistics of the industry, trade and services, this database contains information on the production value and energy costs of several industrial subsectors in Portugal [annex 3].

Petroleum coke is an extremely illiquid commodity in international markets, most petcoke deals occur outside organized markets making pricing a challenge. Eurostat keeps a database of trades (ii) based on transactions of the custom offices of each EU country. This database contains monthly data on traded quantities and values of petroleum coke (and many other commodities) making it possible to estimate petcoke prices in Portugal. The average price for petcoke transacted in the Portuguese customs during 2011 is available in Figure 2.

3.1.3 APA – Agência Portuguesa do Ambiente

Decreto-Lei n.º 194/2000. D.R. n.º 192, Série I-A de 2000-08-21 regulates the water and air pollution emissions for different types of industrial installations as defined in annex 7 of said law. *Decreto-Lei n.º 194/2000* requires that covered installations must apply for an environmental license (Licença Ambiental). Environmental licenses are a public document made available by APA reporting on several environmental issues, namely, fuel consumption, electricity consumption and installed capacity of combustion systems. In addition, the nature of the document assures that most large fuel consumers in Portugal are required to apply for an environmental license, assuring this project's target companies are almost completely represented in this database.

Due to the large number of documents involved (920 documents, mainly environmental licenses and amendments) this project developed a computer program (using Java language) to automate the data extraction from the environmental licenses. It was possible to gather data from 488 Portuguese companies, in particular identification of the industry sector and estimated consumption of fuel oil, natural gas, LPG and electricity. Results of this process are available in annex 7[1]. Environmental licenses date from 2005 to 2012, the average date is 2008.

3.1.4 Cogen Portugal

Cogen Portugal is a private non-profit association that aims to support energy efficiency through the promotion of Combined Heat and Power (CHP) systems. Cogen Portugal kindly shared a database of CHP installations containing information of district, industry sector, beginning of operation, installed capacity, engine type and fuel used from 173 CHP plants operating in Portugal. This database is available as annex 8 of this document.

3.2 Fuel switching potential

In the context of this work project fuel switching potential is defined as a change in fuel and technology that is able to maintain the same productivity while reducing the costs of the operating party. The ensuing paragraphs objectively characterize the most relevant fuels used in Portugal in terms of price and associated CO_2 costs. In addition, following on the hypothesis that natural gas is a good candidate to substitute oil derivative fuels, fuels will be compared to natural gas.

Liquid Petroleum Gas (LPG) is an oil derivative commonly used in Portugal, LPG is the generic term describing propane and butane, the typical gas cylinder used in for kitchens and water heating. LPG is easily interchangeable with natural gas in most instances transition requires low CAPEX. In 2011 LPG average price in Portugal was 77.5 €/MWh more than twice the average price of natural gas additionally LPG releases 12% more CO_2 to the atmosphere than natural gas. During 2011 141 ktoe of LPG was consumed in Portugal, a potential natural gas market of 59 million € /year (natural gas at 35.9 €/MWh).

Fuel oil is a commonly used industrial fuel, in Portugal it is mainly consumed in industrial boilers and cogeneration plants, in both cases fuel transition is already a common market practice and specialized companies with regular activity in this area exist. During 2011 the average price of fuel oil was 66.1 €/MWh, 84% more expensive than the average price of

[1] The PDF documents retrieved from APA are an electronic annex to this document; they may also be accessed at http://sniamb.apambiente.pt/LAdigital/

natural gas, moreover fuel oil releases 38% more CO_2 to the atmosphere than natural gas. Consumption of fuel oil in industry, services, fishing and agriculture in 2011 was 436 ktoe this represents a prospective natural gas market of 178 million €/year.

Petroleum coke is an oil derivative commonly used in the cement industry, petroleum coke costs roughly 1/3 the price of natural gas but it emits 80% more CO_2. Economics of the tradeoff between petcoke and natural gas are heavily dependent on CO_2 emission costs, but at current CO_2 prices petcoke is far less expensive than natural gas.

Diesel is discarded as energy apt for fuel switching. In 2011 674 ktoe were consumed in the industry, services, fishing and agriculture, 87% of which in construction, mining, services and fishing. This is consistent with the assumption that diesel is mainly consumed in internal combustion engines of cars, boats and construction apparel. A fuel transition of this type is outside the scope of this project.

According to descriptions present in environmental licenses of several companies, biomass used in industry is composed of recycled agricultural products like cork dust, olive bagasse and other residue. When locally available biomass is both an inexpensive and clean energy source, this leaves no incentive to promote fuel switching in this area.

Black liquor is an industrial residue, a by-product of the paper pulping industry. It is the main source of energy in of the paper industry. Due to its readily availability the replacement of black liquor is not an option.

Figure 2 compiles information on selected fuel prices over the last decade. In 2011 the average Portuguese no-tax sale price of petroleum coke, natural gas, fuel oil (1% sulfur) and LPG where respectively 13.0, 35.9, 66.1 and 77.5 €/MWh. Though in the future the large price difference between natural gas and fuel oil may be mitigated it is not expected to disappear, for example the forward price of fuel oil in 2015 is 17% more expensive than natural gas, see Figure 3. Market price of electricity production (does not include costs of transport, distribution or power guarantee) is superimposed to demonstrate that electricity is more expensive than natural gas and will not be considered as a substitute.

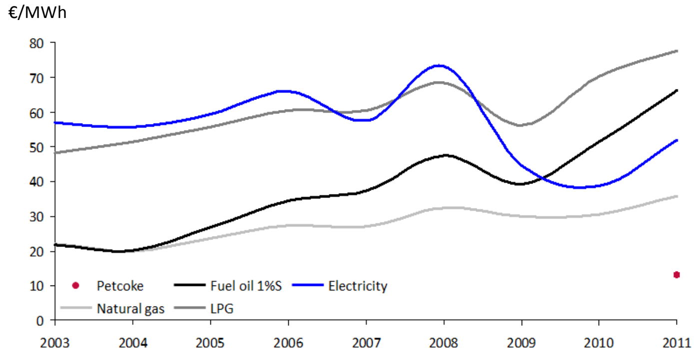


Figure 2 – Yearly average no tax sale price of selected energy sources in Portugal
Source: DGEG, EUROSTAT

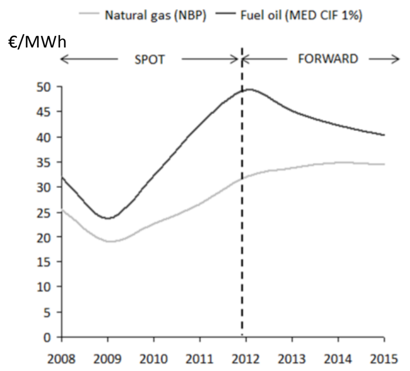


Figure 3 – Natural gas vs Fuel oil – spot and forward
Source: Bloomberg

Currently there is still a lot of uncertainty regarding the future of CO_2 trading schemes, currently CO_2 ETS are trading at 7 €/ton CO_2 (Thomson Reuters, 2012), forward rates for 2017 indicate a price of 9 €/ton CO_2, while European Union has a target price of 16.5 €/ton CO_2 (European Comission, 2012). To estimate impact of CO_2 emissions on fuel costs it is assumed that average price of CO_2 in the next years is 10 €/ton CO_2, using emission factors of 363, 202, 279 and 227 kg CO_2/MWh for petroleum coke, natural gas, fuel oil (1% sulfur) and LPG respectively [annex 2] the CO_2 emission costs are 7.3, 4.0, 5.6 and 4.5 €/MWh respectively. Table 1 characterizes the complete costs associated to each fuel.

	No tax fuel price Portugal 2011 (€/MWh)	CO_2 costs at 10 €/ton CO_2 (€/MWh)	Total (€/MWh)
Petroleum coke	13.0	7.3	20.3
Natural gas	35.9	4.0	39.9
Fuel oil	66.1	5.6	71.7
LPG	77.5	4.5	82.0

Table 1 – fuel costs including CO_2

Despite being clear that petroleum coke is a low-cost energy source when only fuel and CO_2 expenditures are considered, petroleum coke brings unsurpassable logistical cost for most companies. Inexpensive petcoke is available to large consumers which may benefit from synergies stemming from large scale operations, such as Cimpor that in 2012 invested 47 million € in two ships used to export cement and to import petcoke (Cimpor, 2012). Moreover petcoke is extremely pollutant [see annex 2] and not readily available. Petcoke has been extensively used in the cement industry its inclusion in this benchmark targets the possibility of transition from petcoke to natural gas.

It follows that sectors with high LPG, fuel oil and petroleum coke consumption will be examined in greater detail. More specifically DGEGs subsectors (subsectors defined in annex 1) in which consumption of any of this fuels exceeds 20 ktoe, namely, *Food beverages and tobacco, Textiles, Pulp and paper, Chemicals and plastics, Cement, Wood and wood articles, Metal machinery* and *Services*.

3.3 Sector profiling

To identify economic sectors most prone to fuel switching this project followed a methodology of disaggregating national energy balances into economic subsectors. Analysis started with an overview of the Portuguese energy balance. Table 2 expresses this overview for 2011. In 2001 total consumption of primary and final energy in Portugal is estimated at 22236 ktoe and 16514 ktoe respectively, the share of final energy consumed by the Portuguese industry was estimated at 4685 ktoe, 869 ktoe of which were oil and oil derivatives. Services, agriculture and fishing (categorized as Others) registered a final energy consumption of 2321 ktoe of which 535 ktoe were oil and oil derivatives. Combined heat and power which is also a target for fuel transition is classified as Energy transformation in table 2.

		Oil & oil derivatives	Natural gas	Coal	Electricity	Heat	Other [3]	Total
Energy transformation	**Transf. to new forms of energy**	571	2.870	2.201	-2.640	-1.655	1.599	1.347
	Energy sector consumption	560	133	-	595	284	-	1.572
Final energy	**Transport**	5.955	13	-	34	-	4	6.002
	Industry	869	1.052	20	1.396	1.348	653	4.685
	Residential	587	259	-	1.183	-	769	2.029
	Other [1]	535	218	-	1.545	23	51	2.321
Non energy use [2]		1.254	-53	2	-	-	1	1.203

	Oil & oil derivatives	Natural gas	Coal	Electricity	Heat	Other	Total
Primary energy	**10.331**	**4.492**	**2.223**	**2.113**	**-**	**3.077**	**22.236**
	46%	20%	10%	10%	0%	14%	
Final energy	**7.946**	**1.542**	**20**	**4.158**	**1.371**	**1.477**	**16.514**
	48%	9%	0%	25%	8%	9%	

Table 2 – Portuguese energy balance in 2011 (ktoe)
Source: Energy balance DGEG 2011
(1) Services, agriculture, fishing and non-specified
(2) Includes corrections
(3) Industrial residue, solar thermal, biomass, black liquor and other renewables

Analysis continued with the disaggregation of data contained in table 2 into a finer texture, annex 1 shows the result of this procedure. Major sectors were segmented in different subsectors and the section *Others* [table 2] was decomposed into *services*, *fishing* and *agriculture*. Combined heat and power (CHP) facilities affect to any of the relevant segments were moved from the *Energy transformation* sector in table 2 and added to the subsector to which the cogeneration plant belongs to. The resulting annex 1 is a textured summary of the energy balance for *industry, services*, *agriculture* and *fishing*.

Additionally to the partition into economic subsectors, fuel types were also segmented. Annex 1 shows that *Oil & oil derivatives* disaggregate into four main fuel groups. LPG, diesel, fuel oil and petroleum coke with a respective total fuel consumption (CHP plus SHP) of 141, 674, 436 and 375 ktoe, a total of 21% of all energy consumption for the sectors. Biomass with 753 ktoe and black liquor with 878 ktoe consumption represent 20% of the energy requirements of the industry, services, fishing and agriculture, as noted before these fuels will not be considered for fuel transition, still their importance to the energy balance is worth noting.

The next step of data analysis was the creation of time series charts from which it is possible to perceive the evolution of fuel consumption as segmented in annex 1. Figure 4 and Figure 5 (displayed and analyzed in chapter 4.1) display respectively the separated heat and power (SHP) and combined heat and power (CHP) time series of fuel and electricity consumption in the Portuguese industry, services, agriculture and fishing sectors. Similar charts were created for relevant subsectors and are analyzed in the results section.

Finally this project used two databases of individual companies, the APA database and the COGEN Portugal database, summarized respectively in annex 7 and annex 8 of this document, to help gain some more detailed insight into the data contained in annex 1. From the APA database it was possible to identify fuel consumption patterns and installed capacity of companies in the *Food, Beverages, and Tobacco* subsector. This in turn allowed to estimate the load factors of these facilities, an important input for the economic modeling. From the COGEN database it was possible to identify individual instances of combined heat and power allowing an estimation of average size and age of CHP installations both relevant factors to the economic modeling of fuel substitution, as they are key inputs to model cogeneration feed-in tariffs.

3.4 Project valuation

To help evaluate the economics of fuel transition a project finance simulator was developed. It uses the WACC discounted cash flow model taking as input the marginal cash flows originated by fuel switching. The model makes use of the weighted average cost of capital (WACC) discount cash flow model as defined in *Corporate Finance by Hillier, Ross et al.* (David Hillier, 2010).

$$\sum_{t=1}^{\infty}\frac{UCF_t}{(1+R_{WACC})^t} - initial\ investement, \quad R_{WACC} = \frac{B}{S+B}R_B(1-t_c) + \frac{S}{S+B}R_S$$

$$R_S = R_F + \beta R_P$$

Where UCF_t is the unlevered cash flow at period t, B and S are respectively the debt and the equity of the company investing in the project, t_c is the tax rate, R_B is the cost of debt, R_S is the cost of equity, R_F is the risk free rate in Portugal, R_P is the capital market risk premium and β is the company's beta.

This model was used to evaluate fuel switching opportunities for existing fuel oil boilers and combined heat and power (CHP) plants. For fuel oil boilers the model evaluated an upgrade to a natural gas boiler. For existing CHP plants the evaluation focuses on four possibilities, the upgrade of an engine to natural gas, the upgrade of an engine to a dual fuel engine, the installation of a new CHP Otto engine or the installation of a new CHP gas turbine.

The simulation accounts for the marginal change in costs and revenues of a technology switch that maintains the same heat outputs, meaning the old facility produces exactly the same quantity of heat as the new facility. The new facility does not necessarily consume the same amount of fuel or, in the case of CHP, produce the same amount of electricity as the old one.

Marginal change in revenues arises exclusively from different feed in tariffs paid for electricity produced in CHP plants. Tariffs were modeled in the simulator in accordance to *Decreto Lei 23/2010 de 25 de Março* and *Lei 19/2010 de 23 de Agosto and Portaria 140/2012 of de 14 de Maio.* Feed in tariffs for CHP plants are paid for a period of 20 years since the plant starts to operate, economic modeling assumes cogenerations operate since 1996, corresponding to the average age of CHP Diesel engines in annex 8.

Marginal changes in costs are the result of changes in fuel type, maintenance costs, machine efficiencies and of CO_2 emission prices. Prices of fuel oil and natural gas prices were kindly made available by EDP Energias de Portugal, the information is confidential and a reference cannot be provided. Maintenance costs summarized in annex 6 were gathered from Catalog of CHP technology (U.S. Environmental Protection Agency, 2008) and from a seminar on engine conversion (Antunes, 2012). Also summarized in annex 5 are the energy efficiencies of the different technologies. Different CHP facilities have different thermal and electric efficiencies and different boilers have different thermal efficiencies. The model integrates the efficiencies of each CHP technology (U.S. Environmental Protection Agency, 2008) and the thermal efficiencies of the different boilers (Parlamento Europeu, 2006). Finally, despite some uncertainty about the absolute cost of CO_2 emissions for companies, since it is not clear who will receive free licenses, it seems certain that avoided emissions will result in marginal benefit since CO_2 emission rights can be traded in international markets. Marginal CO_2 costs are calculated using emission factors in annex 2 and emission rights priced at the ETS forward prices until 2017 increased at inflation rate for posterior dates.

To estimate CAPEX of each project several sources were available, summary of CAPEX values utilized are available in annex 5. For CHP engine conversions, data from COGEN Portugal was used (Antunes, 2012). Boiler upgrade CAPEX was made available by EDP Serviços. CAPEX for the installation of new CHP facilities was estimated from previous projects, the information is publically available [summarized in annex 4] from Finertec Energia (Finertec Energia SPGS S.A.) and Sociedade Térmica de Gestão (Endesa Portugal).

Inflation rate until 2017 is derived from IMF estimations for Portugal (International monetary fund, 2012) and set to 2% beyond that period. European central bank set 2% as the target inflation rate.

The tax rate (IRC) used in the model was 29.5% this value is in accordance with article 87th and 87th-A of CIRC (Autoridade tributária e aduaneira) and article 14th of *Lei n.º 2/2007. D.R. n.º 10, Série I de 2007-01-15* for companies with a total IRC between 1.5 M€ and 10 M€.

Investment in new equipment was depreciated linearly over a 14 year period, following guidelines for boiler installations set in code 2115 from table I of *Decreto regulamentar 25/2009 de 14 de Setembro* from *Diário da república 1ª serie nº 178*.

4. Results

The results section is divided into three sections. (i) An overview of the evolution of the Portuguese energy balance, (ii) sectorial analysis of relevant economic subsectors and profiling of economic subsectors with high fuel switching potential and, (iii) economic validation of fuel switching candidates.

4.1 Energy balance

Figure 4 and Figure 5 show fuel and electricity consumption of industry, construction, mining, services, agriculture and fishing over the last decade. Figure 4 shows the fuel and electricity consumption of separated heat and power (SHP) facilities while Figure 5 shows fuel consumption in the combined heat and power (CHP) facilities and its respective electricity production.

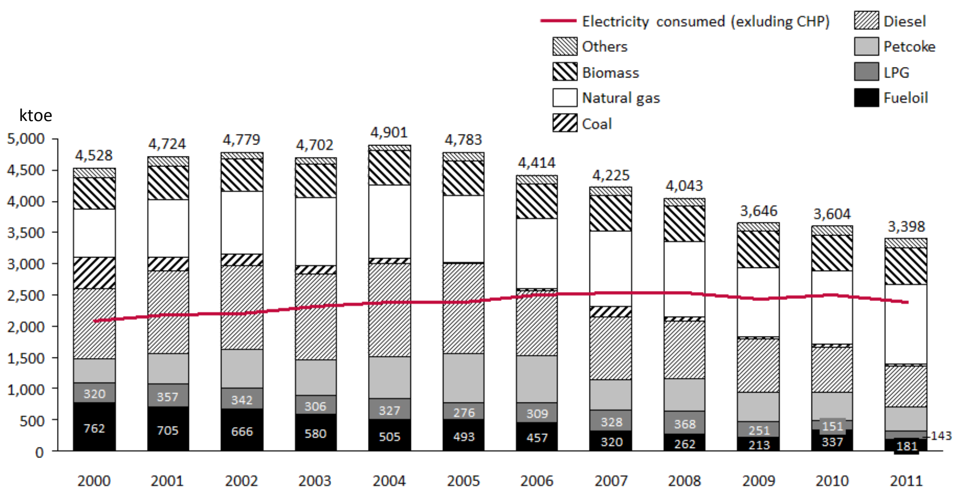


Figure 4 – SHP fuel and electricity consumption in industry, construction, mining, services, agriculture and fishing (ktoe)
Source: DGEG energy balance 2000-2011

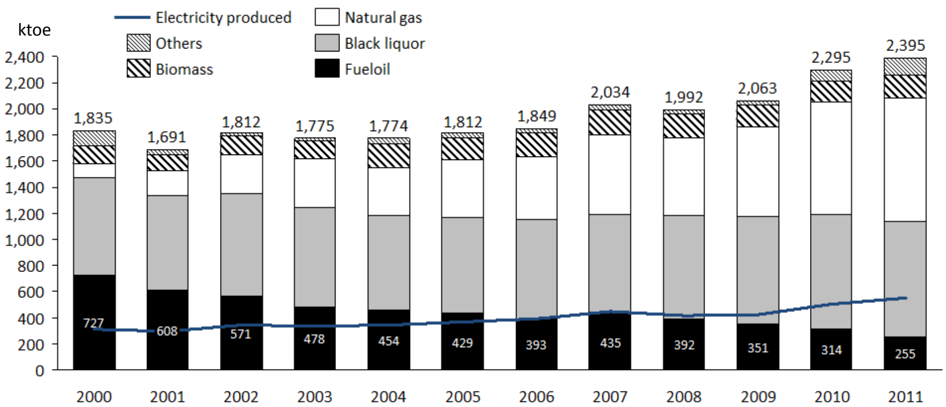


Figure 5 – CHP fuel and electricity consumption for industry, construction, mining, services, agriculture and fishing (ktoe)
Source: DGEG energy balance 2000-2011

It is possible to identify two distinct periods, 2000 to 2005 and 2006 to 2011. The period from 2000 to 2005 is marked by an overall increase in energy consumption, total energy consumption surged from 8496 ktoe in 2000 to 9101 ktoe in 2005. This growth is mainly due to a rise in SHP fuel and electricity consumption. CHP fuel consumption was constant throughout the period. The period 2005 to 2011 is marked by two trends, a strong decrease in energy consumption and a technology shift from SHP to CHP. The consumption decrease is likely the result of the economic downturn of recent years which brought energy consumption down from 9101 ktoe in 2005 to 8186 ktoe in 2011. The conclusion that there was a shift from SHP to CHP in the period from 2005 to 2010 is supported by the fact that d CHP fuel consumption registered a marked rise during the second half of the last decade while fuel consumption in SHP facilities decreased 29% from 4783 ktoe in 2005 to 3398 in 2011. The period spanning from 2000 to 2011 registered strong gasification, the total natural gas consumption rose from 867 ktoe in 2000 to 2219 ktoe in 2011, an 8.9% CAGR. Conversely fuel oil and LPG consumption decreased significantly. The above facts suggest a fuel switching trend has been underway during the last decade, in particular fuel oil and LPG are being replaced by natural gas.

Electrification[2] is also a strong trend of the last decade, growing from 28% in 2000 to 36% in 2011. Parallel to electrification is the increase in distributed power production with a strong increase in electricity production in the industry's CHP plants.

As identified earlier fuel oil seems to be a great candidate for fuel switching. In reality, we can verify that this has been true for the last decade, as consumption decreased from 1489 ktoe in

[2] Electrification in this instance is defined as $\frac{Electricity\ consumption\ CHP\ and\ SHP}{Total\ fuel\ consumed + Electricity\ consumption\ excluding\ CHP}$

2000 to 436 ktoe in 2011. Of the 436 ktoe of fuel oil consumed in 2011 181 ktoe were used in SHP facilities while cogeneration engines combusted 255 ktoe. Another fuel switching candidate, liquid petroleum gas (LPG), also registered a steep drop in consumption during the last decade. In 2000, 320 ktoe of LPG were used while in 2011 only 143 ktoe were consumed. Unlike fuel oil, LPG does not register any consumption in CHP facilities. Petroleum coke utilization patterns can be divided into two periods. The first, from 2000 to 2005, in which consumption increased from 394 ktoe to 792 ktoe and the second, from 2005 to 2011, when consumption decreased from 792 ktoe to 375 ktoe. Fuel oil and LPG consumption have been decreasing since the beginning of the decade in line with the increase consumption of natural gas indication that a transition from fuel oil and LPG to natural gas is underway. On the other hand the reduction in the consumption of petroleum coke only happens since 2005 in line with the decrease of the overall demand for energy favoring the hypotheses that petcoke consumption reduction might not have been substituted.

Despite last decade's strong drop in LPG and fuel oil consumption at the current price of natural gas, 35.9 €/MWh, the LPG market is evaluated at 59 million €/year while the fuel oil market is estimated to be worth 178 million €/year.

Following the metric established in chapter 3.2, the subsectors (present in annex 1) in which fuel oil, LPG and petroleum coke have a consumption larger than 20 ktoe will be analyzed for fuel switching potential. From annex 1 it is possible to verify that in 2011 fuel oil was consumed in excess of 20 ktoe in the *Food beverages and tobacco*,119 ktoe, *Textiles*, 74 ktoe, *Paper & pulp,* 59 ktoe, *Chemicals and Plastics*, 57 ktoe, *Services,* 33 ktoe , *Wood and wood articles,* 32 ktoe and *Construction,* 21 ktoe. LPG was consumed in excess of 20 ktoe in the Services, *48 ktoe,* the *Food beverages and tobacco*,22 ktoe and the *Metal machinery* , 21 ktoe. Petcoke was almost exclusively consumed in the *Cement* subsector with 362 ktoe consumed in 2011.

4.2 Sector analyses

4.2.1 Food, beverages and tobacco

Food, beverages and tobacco sector is composed of vast array of different products and industry processes. On average energy represents 4.2% of the costs of industry [annex 3], but costs of specific subsectors vary substantially. In *fruit and vegetable processing* energy represents 8.3% of costs, for *sugar* this value is 6.6%, for *beer* 3.3% while in *dairy* the it is 4% [annex 3].

Despite not having high share of energy costs as a whole, the *Food, beverages and tobacco* subsector (*food* sector from here on) has some segments that do have high energy costs.

Figure 6 lays out the yearly energy mix used by SHP technologies in the *food* sector from 2000 to 2011. Total SHP energy usage increased slightly in the beginning of the last decade but retracted back to 2000 levels in 2004, and has registered no significant changes since then. Electricity consumption increased at a steady rate of 1.3% per year. The last decade saw some changes in SHP fuel mix composition. Since 2000 LPG dropped 46% to 22 ktoe, fuel oil dropped 58% to 69 ktoe while natural gas increased from 23 ktoe in 2000 to 116 ktoe in 2011. This pattern indicts a fuel switch trend from LPG and fuel oil to natural gas.

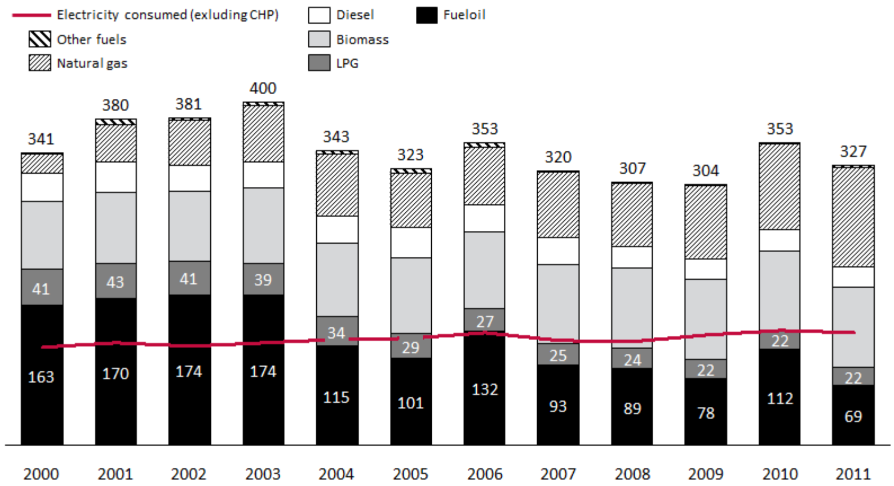


Figure 6 – SHP fuel and electricity consumption in the Food, beverages and tobacco industry sector (ktoe)
Source: DGEG energy balance 2000-2011

Of the total fuel consumed in 2011, 27% was in CHP facilities. Figure 7 portrays the last decade of CHP fuel usage in the *food* sector. Cogeneration fuel consumption increased substantially in 2007 but remained stable otherwise. Consumption of natural gas increased from 20 ktoe in 2000 to 69 ktoe in 2011. Fuel oil does not register a clear trend, there are some year to year variations but essentially consumption has remained stable over the last decade. Despite significant fuel transition in the food sector, when compared with the textiles or the chemical industries fuel mix evolution, fuel switching is still moderate. It is clear that there is still substantial operational capacity consuming fuel oil.

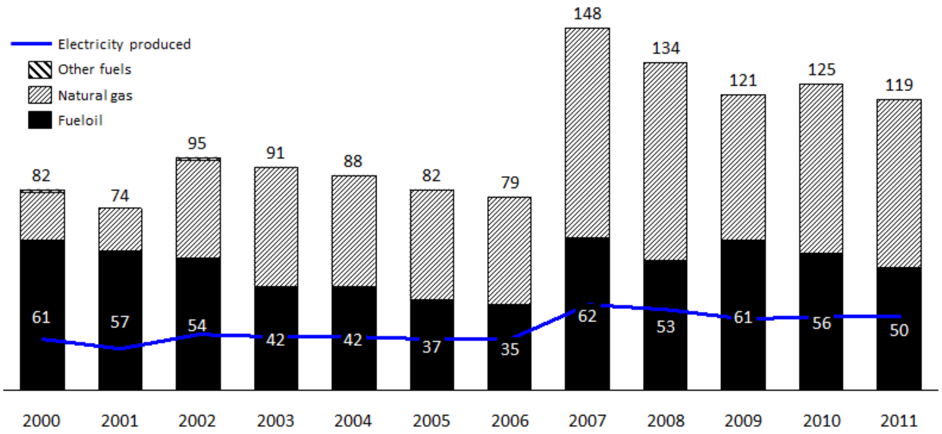
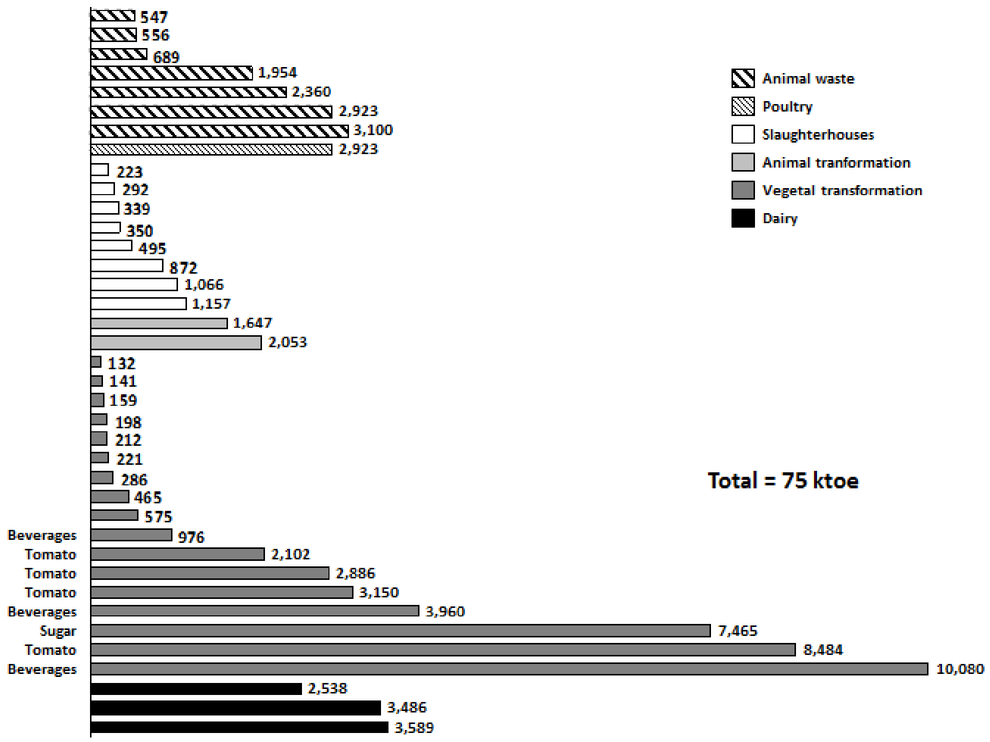


Figure 7 – CHP fuel consumption and electricity production in the Food, beverages and tobacco industry sector (ktoe)
Source: DGEG energy balance 2000-2011

Figure 8 shows yearly usage of large fuel oil consumers in the food sector. Data dates to 2008[3] and accounts for 75 ktoe of the total 142 ktoe fuel oil consumed during 2008 in the food sector, covering 53% of all fuel oil consumption in this sector and accounting for the most significant consumers. Animal waste, poultry, slaughterhouses and animal transformation sectors use fuel oil mainly in boilers [see environmental licenses 285/2011, 301/2009, 411/2011 and 361/2010 for example]. Dairy industrialists also use boilers and in some cases a cogeneration [see for example environmental license 1/2005 or 67/2008]. Vegetal transformation subsector can further be divided into subgroups; in this subsector the largest fuel oil consumers belong to the beverages, tomato or sugar industry as marked in Figure 8. The beverages industry utilizes boilers and cogeneration technology [environmental license 12/2006 and 45/2006]. Tomato industry uses only boilers as part of the industrial process [environmental license 128/2008 or 5/2006 for example]. The remaining companies of the vegetable transformation group generally use fuel oil in boilers without cogeneration, the exception is the sugar refining industry that typically has a cogeneration unit.

[3] 2008 is the average year of the data sources, see section 3.1.3 for details.



Only companies available in the APA database with fuel oil consumption greater than 100 toe are displayed (toe)
Source: (APA Agência Portuguesa do Ambiente)

LPG consumption of individual industrial facilities is exhibited in Figure 9. Three subsectors stand out, the poultry industry, slaughterhouses and vegetal transformation. In the poultry industry LPG is mainly used in the heating system of poultry pavilions [see environmental license 179/2008, 294/2009 or 431/2012 for example]. Slaughterhouses use LPG in burners to remove hair from animals [environmental licenses 54/2008 and 125/2008 for example]. Vegetal transformation uses LPG mainly in boilers [environmental licenses 18/2005 and 7/2006].

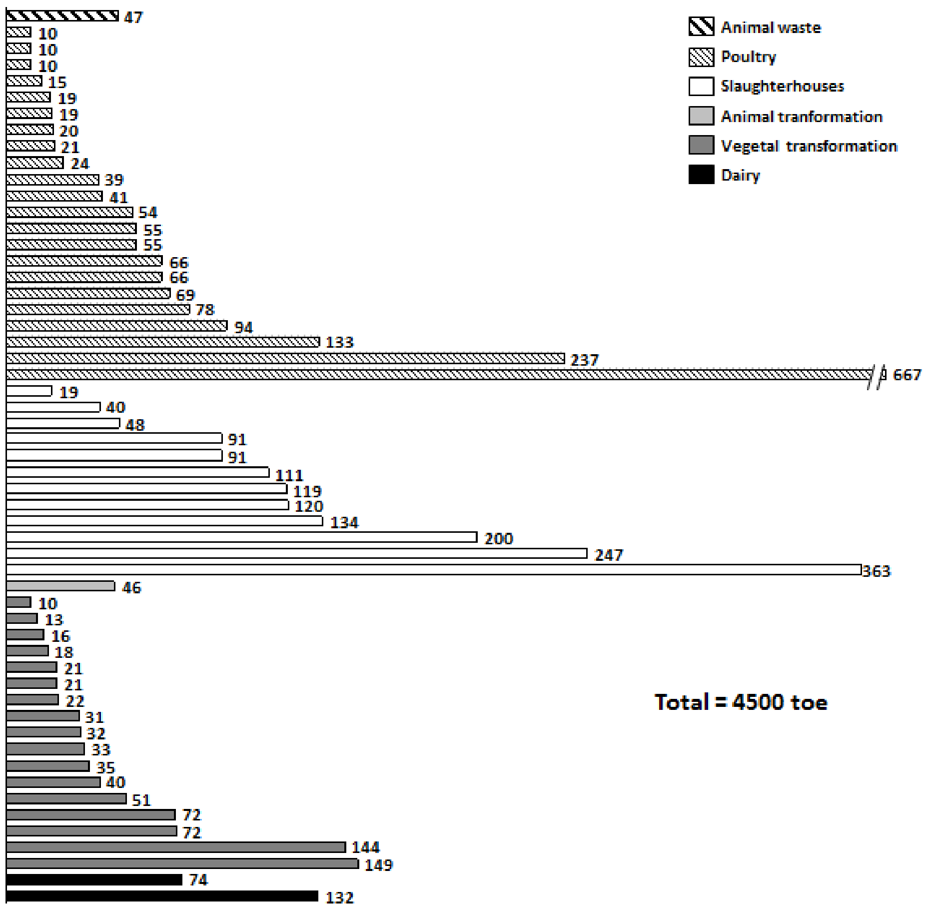


Figure 9 – LPG consumption of companies from Food, beverages and tobacco sector in 2008 (toe)
Only companies available in the APA database with LPG consumption greater than 10 toe are displayed
Source: (APA Agência Portuguesa do Ambiente)

In summary, during the last decade there has been a transition from fuel oil and LPG to natural gas. Despite this fact there is still a good array of fuel switching opportunities in the sector, in particular there is large potential in the transition from fuel oil to natural gas in boilers and cogeneration plants.

4.2.2 Paper and Pulp

Paper industry has several unique characteristics in its energy consumption profile. In 2011 the Portuguese paper industry consumed 1555 ktoe of fuel, 7% of which in SHP facilities and 93% in CHP plants. Paper CHP facilities produced in 2011 302 ktoe (3500 GWh) of electricity, 7.2% of all electricity produced in Portugal. These results were achieved using mainly biomass and black liquor 154 ktoe 878 ktoe respectively, both derivatives from the industrial process. In 2010 11.5% of the paper industry costs were due to energy products [see annex 3], in particular in the manufacture of pulp and paper energy represents 13.6% of the costs, suggesting sector sensitivity to energy prices.

Figure 10 and Figure 11 show last decade's evolution of the energy mix in the *Paper and Pulp* industry (*Paper* industry from here onwards) for SHP and CHP technologies. The industry's fuel mix has not registered substantial changes over time. In SHP technology there is a trend to increase usage of natural gas while CHP has verified a pattern of increased consumption of natural gas and reduced consumption of fuel oil. Fuel oil is again a candidate for a fuel transition to natural gas. Natural gas is cheaper, cleaner, readily available and there are no technological or logistical barriers to transition. In 2011 the paper sector used 59 ktoe of fuel oil, 29 ktoe of which in SHP technology and 30 ktoe in cogeneration plants. Throughout decade CHP fuel oil consumption gradually decreased, it went from 259 ktoe in 2000 to 30 ktoe in 2011. SHP fuel oil consumption has been stable, registering only a slight increase over the last decade, it went from 25 ktoe in 2000 to 29 ktoe in 2011; 2010 was an outlier with consumption of 69 ktoe. From this data it is possible to conclude that while in CHP technology there is active reduction of fuel oil consumption, in the SHP facilities there is no such trend. Finally note that fuel oil represents a very small fraction of the paper industry energy mix, 3.8% of the total energy consumed.

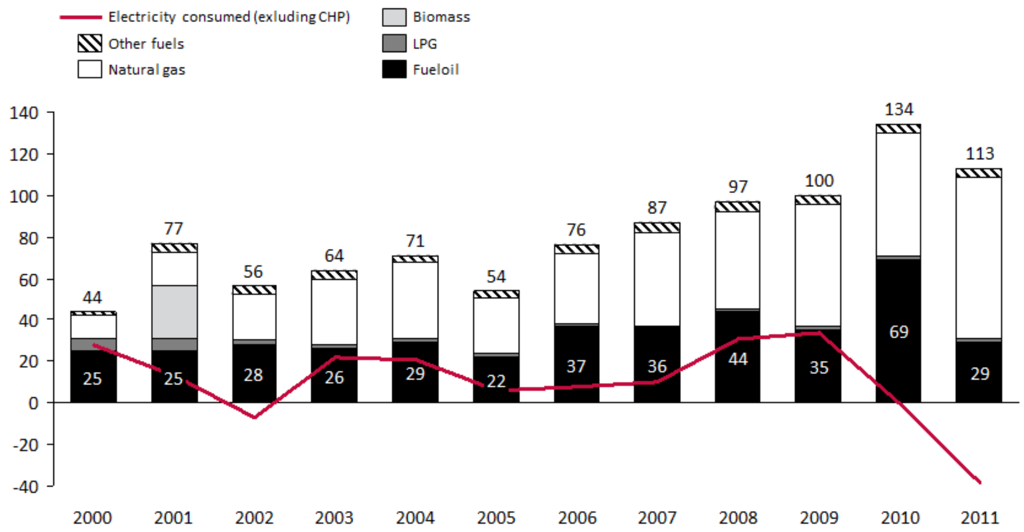


Figure 10 – SHP fuel and electricity consumption in the Paper & pulp industry sector (ktoe)
Source: DGEG energy balance 2000-2011
** Negative electricity consumption implies that the Paper sector has an electricity surplus*

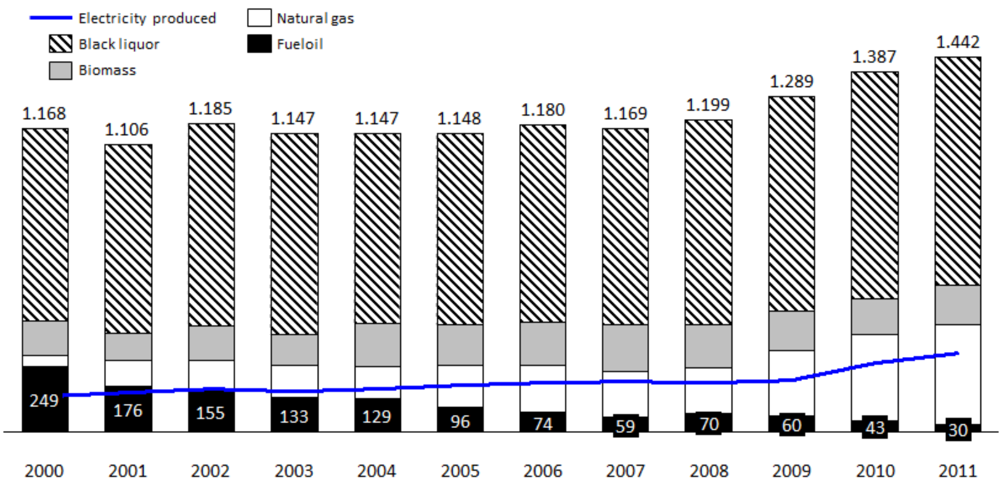


Figure 11 – CHP fuel consumption and electricity production in the Paper & pulp industry sector (ktoe)
Source: DGEG energy balance 2000-2011

Figure 12 summarizes fuel oil consumption of companies available in the APA database. It accounts for 66 ktoe, 58% of the total 114 ktoe consumed in 2008. Environmental licenses indicate that fuel oil usage in the paper industry is done in auxiliary boilers (SHP technology) and as auxiliary fuel for CHP facilities [see for example licenses 426/2012, 29/2005 or 30/2007] pointing to a low potential of fuel oil transition to natural gas. The main reasoning for this conclusion is that fuel oil is mainly used as auxiliary fuel with little impact in the paper industry costs, efficiency or productivity, therefore inducing little incentive for the switching party to initiate a fuel shift.

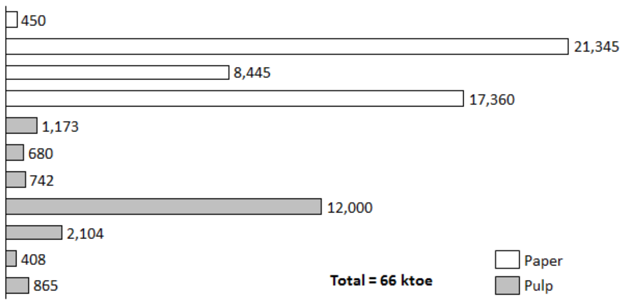


Figure 12 – Fuel oil consumption of companies from Paper & Pulp sector in 2008 (toe)
Only companies available in the APA database are displayed.
Source: (APA Agência Portuguesa do Ambiente)

4.2.3 Textiles

Energy products represented 8.3% of the Portuguese textile sector costs in 2010 [annex 3], indicating a sector sensitive to fuel switching. In 2011 the textile industry used 328 ktoe of fuel and consumed 79 ktoe (919 GWh) of electricity, of which 58 ktoe from own CHP production and 21 ktoe bought from the market operators. SHP used 177 ktoe of fuels while CHP utilized

151 ktoe [see Figure 13 and Figure 14] Fuel mix of SHP systems is composed mainly of natural gas and biomass but there is some residual fuel oil and LPG, 8 ktoe and 3 ktoe respectively. Low consumption of fuel oil and LPG are the result of a gradual decrease in consumption in the course of the last decade. In the SHP technology there is no clear fuel switching pattern from fuel oil and LPG to natural gas as observed in other industries. In this particular case data implies that as the energy requirements of the sector decreased the SHP fuel oil and LPG consumption were disproportionally reduced. Such pattern suggests that as the textile sector faced international competition companies with a heavier cost structure, such as fuel oil consumers, simply ceased to exist. The same is not true for CHP installations where the energy mix registered strong changes, in the last decade we witnessed a strong transition movement from fuel oil to natural gas as it is clear in Figure 14. CHP in the textiles industry transitioned from a consumption of 149 ktoe of fuel oil and 2 ktoe of natural gas in 2000 to 66 ktoe of fuel oil and 85 ktoe of natural gas in 2011.

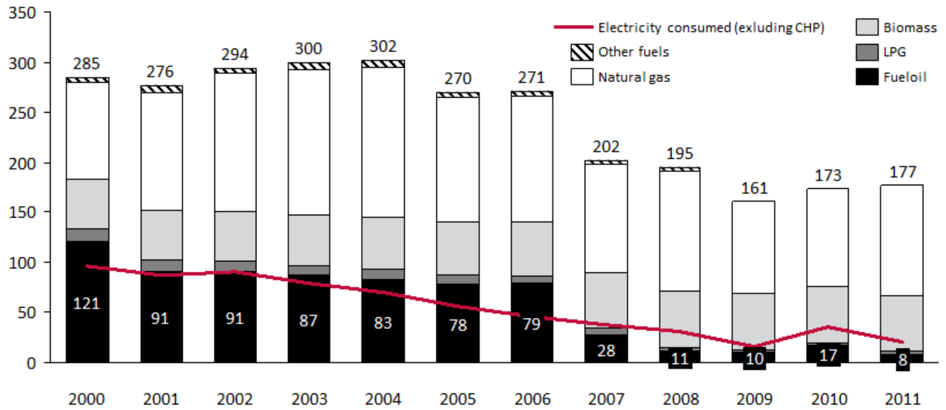


Figure 13 – SHP fuel and electricity consumption in the Textiles industry sector (ktoe)
Source: DGEG energy balance 2000-2011

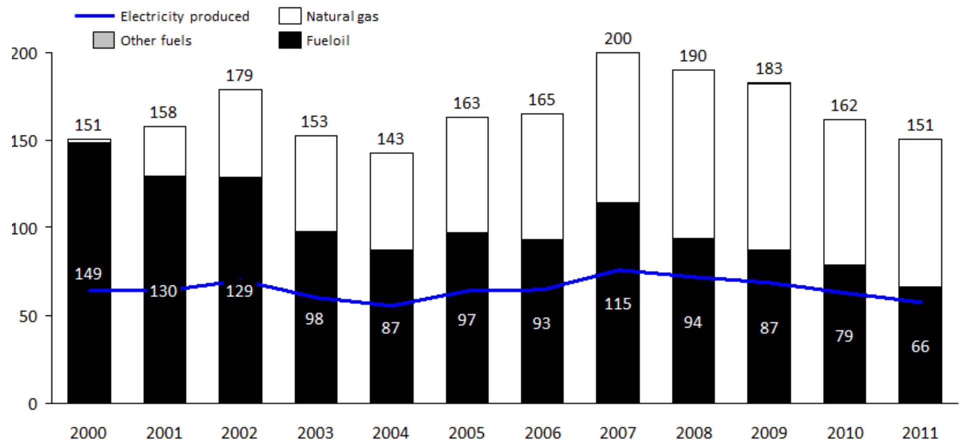


Figure 14 – CHP fuel consumption and electricity production in the Textiles industry sector(ktoe)
Source: DGEG energy balance 2000-2011

Data from COGEN Portugal portrayed in annex 8 indicates fuel transition was achieved mainly through the conversion of existing CHP diesel engines to CHP Otto engines running on natural gas. This database reports 11 complete conversions from fuel oil engines to natural gas in the textile sector, 3 of which in 2012. Additionally COGEN Portugal database reports on the existence of 2 instances where conversion is ongoing, a total capacity transition of 31 MWe just this year. It further reports the existence of 8 cogenerations still running on fuel oil with a total capacity of 35 MWe. Under the assumption that during 2011 these thirteen facilities, consumed 66 ktoe of fuel oil, a *pro rata* on fuel consumption by installed capacity implies a potential market for fuel switching to natural gas of 35 ktoe concentrated in eight CHP installations (tough one is very small).

4.2.4 Chemicals and plastics

In 2010 energy represented 5.5% of the *chemicals and plastics* industry costs [annex 3]. Energy costs are moderate in this sector. The energy overview of the sector is presented in Figure 15 and Figure 16 showing the evolution, over the last decade, of the energy mix for SHP and CHP technology. In 2011 the total fuel consumption of the sector was 523 ktoe, 197 ktoe in SHP facilities and 326 ktoe in CHP plants. Data from Figure 15 points to a low potential for fuel transition in the SHP technology. In 2011 most of the fuel consumed was natural gas and biomass, low switching potential fuels; fuel oil and LPG registered only residual consumptions 5 ktoe and 12 ktoe respectively. Total SHP fuel consumption dropped from 257 ktoe in 2000 to 197 ktoe in 2011, a 23% decline. In particular consumption dropped intensely after 2009 in synchrony with the beginning of the economic crisis. High year-to-year volatility of LPG, gas residues and natural gas consumption is likely to be partially explained by changes in energy classification of some gas residue produced in the *chemicals* sector, this thesis was not able to identify any other satisfactory explanation for this large changes. Fuel oil consumption in SHP facilities has decreased substantially over the last decade, likely the result of substitution for natural gas. In CHP facilities overall consumption has increased from 208 ktoe in 2000 to 326 ktoe in 2011. Consumption increased gradually with exception of large decline in 2008 and 2009, likely the result of economic crisis. The fuel mix of CHP plants has changed substantially, last decade registered a strong gasification pattern in parallel with a gradual decrease of fuel oil as it is patent in Figure 16. Fuel oil consumption went from 156 ktoe in 2000 to 52 ktoe in 2011. Gas residue consumption is likely resultant from the refining process making it a poor fuel switching candidate.

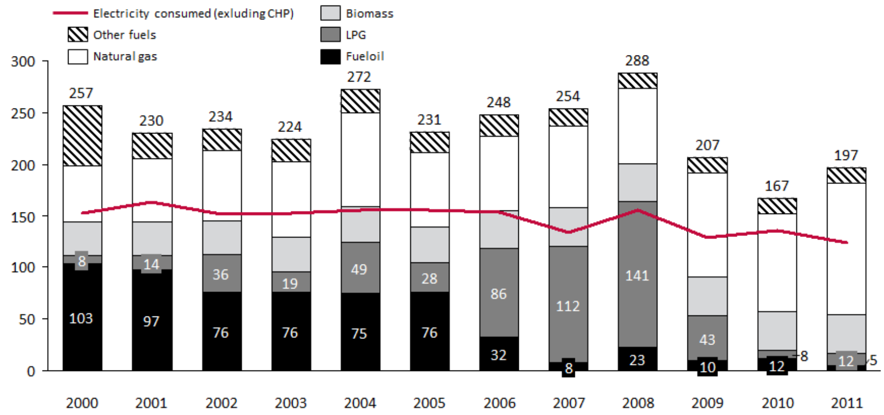


Figure 15 – SHP fuel and electricity consumption in the Chemicals & Plastics industry sector (ktoe)
Source: DGEG energy balance 2000-2011

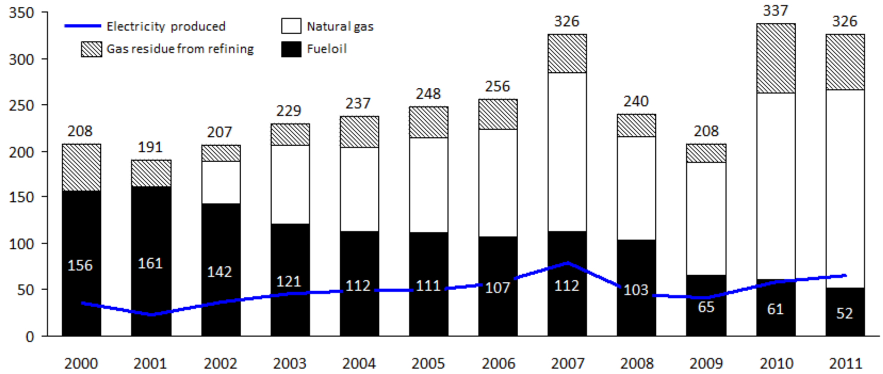


Figure 16 – CHP fuel consumption and electricity production in the Chemicals & Plastics industry sector (ktoe)
Source: DGEG energy balance 2000-2011

Fuel switching potential in the *chemicals and plastics* could happen through a switch from fuel oil to natural gas in some cogeneration plants. Annex 8 identifies 5 CHP facilities in the chemical industry that use fuel oil; the total installed capacity is 67 MWe.

4.2.5 Wood and wood articles

The energy mix for the *wood* sector is available in Figure 17 and Figure 18 for SHP and CHP technologies correspondingly. In 2011 the total fuel consumption for the sector 88 ktoe, 39 ktoe in SHP and 49 in CHP technology. Fuel consumption in SHP is not an attractive fuel switching market, as in the last years the market crystalized into the consumption of natural gas and biomass as portrayed in Figure 17. Figure 18 shows that since 2001 the *wood* sectors' energy mix suffered little change. In 2011 fuel consumption was composed of 17 ktoe of biomass and 32 ktoe of fuel oil.

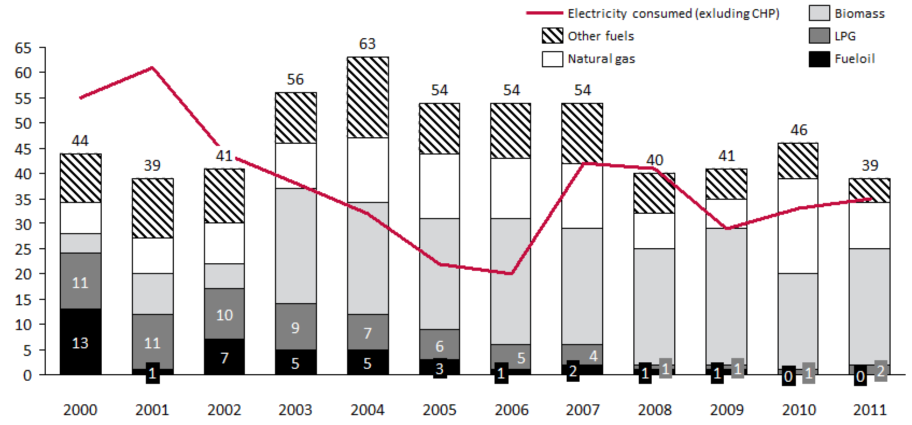


Figure 17 – SHP fuel and electricity consumption in the Wood and wood articles industry sector (ktoe)
Source: DGEG energy balance 2000-2011

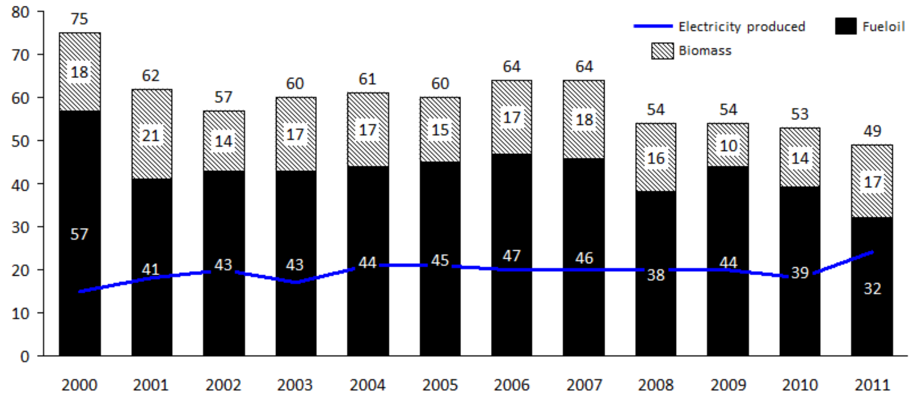


Figure 18 – CHP fuel consumption and electricity production in the Wood and wood articles industry sector (ktoe)
Source: DGEG energy balance 2000-2011

CHP facilities in the wood sector point to a low volume of good fuel switching opportunities. Annex 8 accounts for four fuel oil CHP facilities in the wood sector, with a total installed capacity of 31 MWe.

4.2.6 Metal machinery

Metal machinery sector energy mix evolution over the last decade is portrayed in Figure 19 and Figure 20. Energy consumption in the sector is essentially done in SHP facilities, in 2011 fuel consumption reached 74 ktoe, fundamentally natural gas and LPG with the consumption of 49 ktoe and 21 ktoe respectively. Electricity is the core energy for this sector in 2011 power consumption reached 150 ktoe (1745 GWh). The last decade registered almost constant fuel consumption, with a decline only in the last three years probably a function of the economic crisis, see Figure 19. The SHP energy mix changed noticeably over the last decade, in 2000, fuel oil, LPG and natural gas represented respectively 14%, 49% and 31% of the fuel mix, in 2011 there was no consumption of fuel oil, while LPG and natural gas represented 28% and 66% correspondingly. The pattern indicates a fuel switching movement from fuel oil and LPG to natural gas. CHP facilities use only residual amounts fuels; in 2011 total fuel consumption was 3 ktoe of fuel oil [Figure 20].

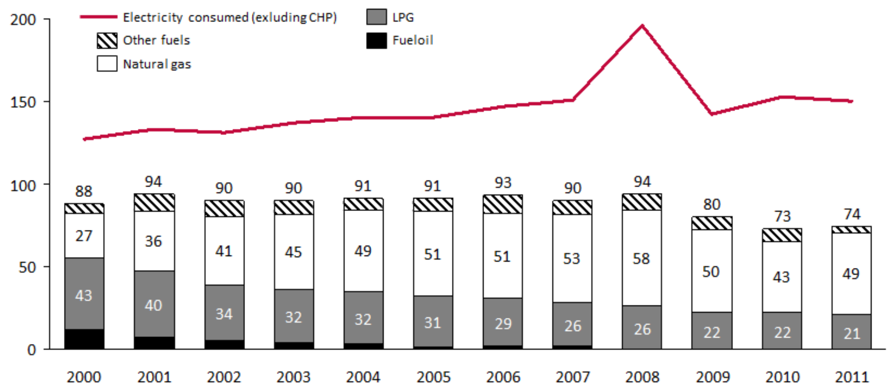


Figure 19 – SHP fuel and electricity consumption in the Metal machinery industry sector(ktoe)
Source: DGEG energy balance 2000-2011

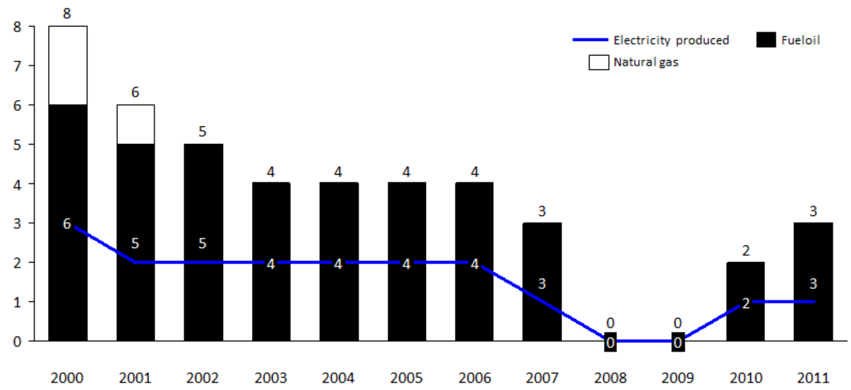


Figure 20 – CHP fuel consumption and electricity production in the Metal machinery industry sector(ktoe)
Source: DGEG energy balance 2000-2011

Annex 9 shows natural gas, LPG and electricity consumption of 86 companies from the metal sector. Total LPG consumption from this group of companies is 7 ktoe, only 27% of total LPG consumed during 2008 in the *Metal machinery* sector. Major conclusions from APA database are: (i) Companies that use natural gas do not use LPG. It is possible that natural gas is not physically available for LPG users. (ii) Metal surfaces and plastics subsector is the best known market for fuel transition. (iii) LPG is used mostly in stove dryers and burners [see environmental licenses 142/2008, 19/2006 or 25/2005 for example].

The sector has fuel switching potential in the transition from LPG to natural gas, the transition should be quite accessible in terms of cost and availability of technology since conversions from LPG to natural gas systems require minimal changes. Lack of natural gas supply could prevent transition in some cases.

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4.2.7 Cement

The *Cement* sector is an energy intensive industry, cost of energy products represents 23.5% of sector costs [annex 3]. Additionally, as a liquid internationally traded commodity, cement pricing is cost based, minimization of energy costs is therefore a priority in the sector. Evolution of the energy balance of the cement sector in the last decade is available in Figure 21 unlike the other subsectors Cement does not use any CHP technology. In the last decade energy consumption decreased substantially, more so after 2008 the start of the economic crisis. In 2000 the sector used 847 ktoe of fuels while in 2011 it used only 494 ktoe. Electricity consumption averages 12% of total energy consumption with small year-to-year variations. In 2011 the cement energy mix in Portugal was 13% electricity, 64% petroleum coke, 14% alternative fuels and 5% natural gas, the last decade saw little change in energy mix, in recent years small modifications occurred through the reduction of coal and the increase of alternative fuels. Also relevant is introduction of natural gas in the mix, see Figure 21.

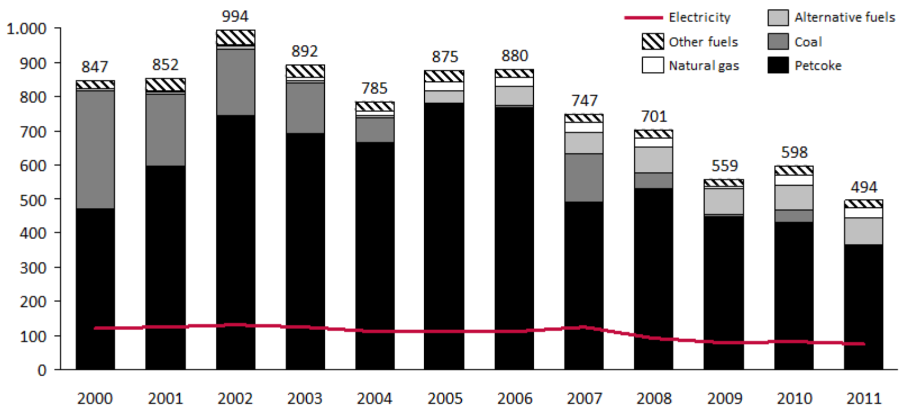

Figure 21 – Fuel and electricity consumption in the Cement sector (ktoe)
Source: DGEG energy balance 2000-2011

Utilization of natural gas to fulfill 5% the *cement* sector energy needs in 2011 prompted the question of whether there would be room for a transition from petroleum coke to natural gas. To address this issue this project collected data on the energy mix of the *cement* industry in Spain, France, Germany and the US. Results are available in Figure 22.

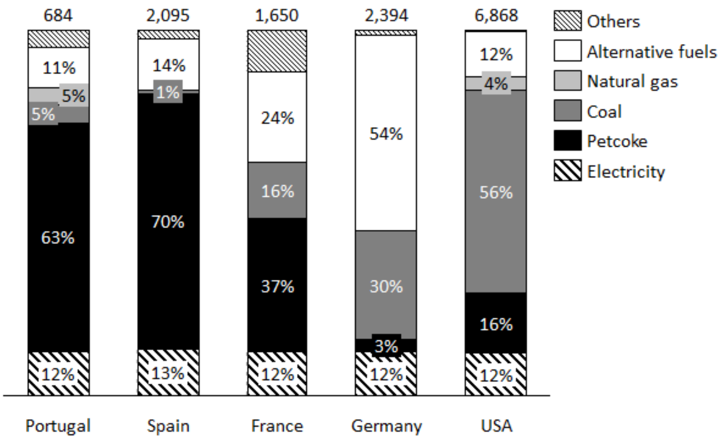

Figure 22 – Benchmark of energy mix in the Cement sector for 2010. Portugal, Spain, France Germany and USA (ktoe)
Source: DGEG, USGS, OFICIMEN, VDZ, INFOCIMENTS

Outcomes of the benchmark are unambiguous, natural gas is not a commonly used energy source in the cement industry. In Europe none of the studied countries uses natural gas in significant quantities. Only the US has some use of natural gas, 3.8% of the energy mix, still not sufficient to induce further analysis. The benchmark allowed the identification of uniformity in the weight of electricity consumption across the different geographies, in all the studied cases electricity provides approximately 12% of the total energy requirements. Other interesting results stemmed from the use of alternative fuels (tires, biomass, industrial residue…), which are a major source of energy in the German *cement* industry where they account for 54% of the energy requirements, in France 24% of the energy needs are met through the use of alternatives, in Spain 14% and in Portugal 11%. There is a geographical axis between Germany and Portugal along which alternative fuel consumption decreases.

In conclusion, there seems to be no room for an increase in the utilization of natural gas in the Portuguese cement industry. Data suggests there may be opportunity for an increase in alternative fuels; the evaluation of this transition is outside the scope of this project.

4.2.8 Services

Energy consumption in the *Services* sector is illustrated in Figure 23 and Figure 24. Energy is mainly consumed in SHP technology; in 2011 the sector consumed 341 ktoe of fuels and used 1461 ktoe of electricity. Natural gas was the main fuel used, 214 ktoe, fuel oil and LPG consumption was respectively 28 ktoe and 48 ktoe. The total amount of fuel consumed has been fairly constant during the last decade. The same is not true for the energy mix; for the last decade natural gas has been replacing fuel oil and LPG, see Figure 24. CHP fuel consumption is residual.

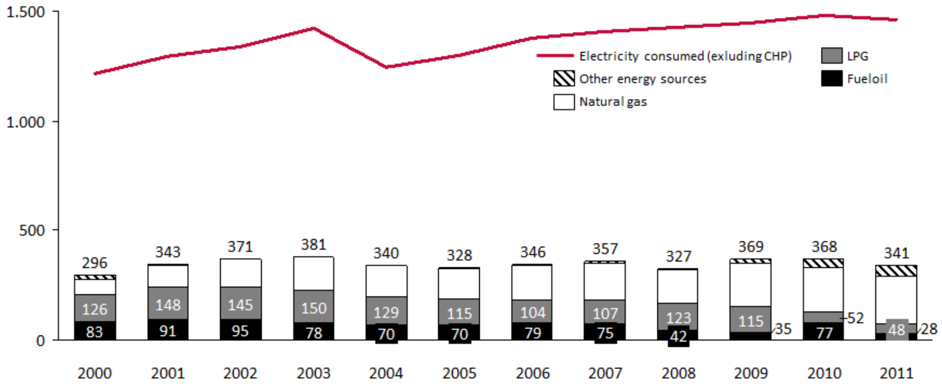

Figure 23 – SHP fuel and electricity consumption in the Services sector (ktoe)
Source: DGEG energy balance 2000-2011

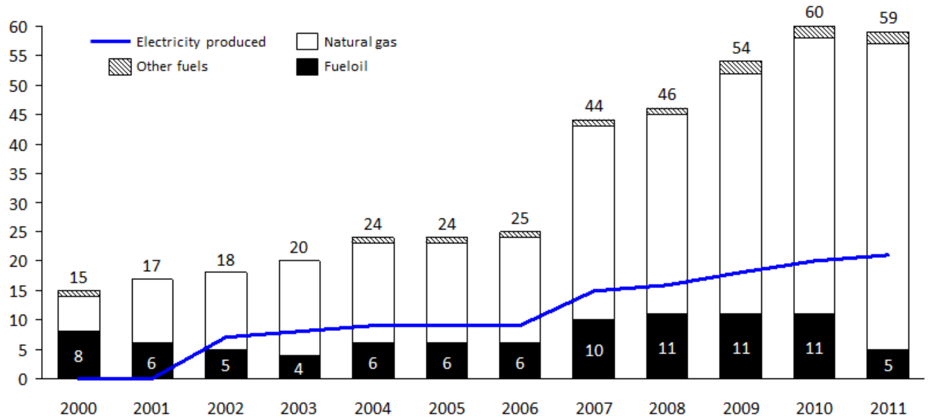

Figure 24 – CHP fuel consumption and electricity production in the Services sector (ktoe)
Source: DGEG energy balance 2000-2011
** Diesel, gasoline and jet fuel consumption was removed from the chart; usage varies wildly over the years likely the result of classification issues between the services and the transport sector.*

The *Services* sector has fuel switching potential, the trend in the reduction of LPG and fuel oil consumption matched by an increase in natural gas is expected to continue. Detailed data on the installed capacity of heating systems in services buildings is available in ADENE.

Unfortunately this data was unreachable in the context of this project. Despite that fact it is likely, taking into account clues from other industry sectors, that fuel oil is mostly used in services buildings' HVAC boilers. LPG on the other hand is likely used for both heating and cooking purposes.

4.2.9 Summary of sector analyses

There are two main segments of energy consumption patterns prone to fuel switching to natural gas, consumption of fuel oil in boilers and consumption of fuel oil in CHP plants. Additionally it there are several different occurrences (slaughter house burners, kitchens, dryers…) of LPG consumption. Table 1 summarizes the main findings of the sectorial analysis.

	Fuel Oil - Boiler (ktoe)	Fuel oil - CHP (ktoe)	LPG (ktoe)	Comments
Food, beverages and tobacco	69	50	20	Excellent fuel switching potential from fuel oil to natural gas, both in CHP Diesel engines and in boilers. Tomato concentrate, dairy, beer and sugar refining are the most relevant targets
Paper & Pulp	29	30	2	In this industry fuel oil is mostly consumed in auxiliary systems or as an auxiliary fuel to start combustion of other fuels.
Textiles	8	66		Excellent fuel switching potential. Database in annex 8 indicates the existence of 7 CHP Diesel engines that could be a target for a conversion to natural gas.
Chemicals and Plastics	5	52	12	Good fuel switching potential. Database in annex 8 indicates the existence of 5 CHP Diesel engines that could be a target for fuel switching.
Wood and wood articles	-	32	2	Good fuel switching potential. Database in annex 8 indicates the existence of 3 CHP Diesel engines that could be a target for fuel switching.
Metal machinery	-	3	21	Annex 9 identifies several large LPG consumers that could be a target for a transition to natural gas, mostly in the metal surfaces treatment and nonferrous metal fusion subsectors. Switching could be limited due to lack of natural gas network
Services	28	5	48	LPG potential could be limited by lack of natural gas distribution network. Consumers are to identify and likely run small scale operations.

Table 3 – Summary of most relevant switching potential

4.3 Economic validation of fuel switching candidates

Section 4.2 identifies two recurring cases of fuel switching opportunities, the fuel oil steam boiler and the CHP diesel engine. In this chapter the economic viability of these two conversions will be modeled assuming generic cases for both instances. Since the food sector offers the greatest fuel switching potential, the generic case will be modeled to mirror the average food sector company. As such the WACC rate for the following cases is set to match average values of this industry sector. Average beta values and debt to equity ratio of US companies are used as an estimator for Portuguese companies, unlevered beta and the debt to equity ratio for the food processing industry in the US are respectively 0.77 and 0.295 (Damodaran, 2012). Risk free rate used for the WACC calculation will be 7.45% the current value of a Portuguese 30 year bond in the secondary market (Bloomberg). Cost of debt is assumed to be 10%, the current economic environment in Portugal is quite volatile and this value will vary substantially for each facility. This project chose to adopt a 2.55% spread over the Portuguese risk free rate. This loose assumption will later be mitigated through a sensitivity analysis of the WACC value. Finally we obtain $R_{WACC} = 11.7\%$.

4.3.1 Economic validation of fuel oil steam boiler switch to natural gas

To appraise the economics of a fuel switching project one must estimate the load factor of the switching facilities. The database of environmental licenses allowed to collect data on the installed capacity and consumption fuel consumption of several facilities of the *food and beverages* subsector, the results of this work are available in table 4. From this data it is straight forward to estimate the load factors is simply the ratio of energy over capacity. Load factors estimated for boilers used in Portuguese companies of the tomato, beverages, sugar and dairy industry, are respectively 825, 1137, 1794 and 2569 hours per year. As it is patent load factors depend heavily on industry, for example tomato concentrate sector is seasonal and most activity occurs between August and October, leading to low load factors.

From section 4.2 it becomes clear fuel oil boilers are still commonly used in the food and beverages sector. Its replacement can be achieved through the upgrade of the existing fuel oil boiler to natural gas. For the base case of 11.7% WACC and a load factor of 1500 hours/year upgrading a fuel oil boiler to natural gas has a NPV of 230 €/kWt and a payback period of 11 months. The NPV is roughly 10 times larger than CAPEX.

	Installed capacity (MW)		Fuel consumption (toe)		Load factor (hours/year)	Industry load factor (hours/year)
	Fuel oil	Natural gas	Fuel oil	Natural gas		
Tomato	37			2102	656	825
	31			2886	1066	
		63	5310		974	
	45			3150	809	
	151			8484	653	
		62	4239		792	
Beverages	43			3960	1061	1137
	71			10080	1663	
	17			976	688	
Sugar		68	10400		1779	1794
	48			7465	1809	
Dairy		5	1080		2563	2569
	12			2538	2439	
	18			3486	2240	
		24	6140		2975	
	16		0	3589	2625	

Table 4 – Boiler thermal capacity, fuel consumption and load factor from selected companies in the food and beverages industry sector in 2008

Figure 25 summarizes a sensitivity analysis along four dimensions, load factor, WACC, CAPEX and spread of fuel oil premium over natural gas. It is clear that this project is robust to variations to its assumptions. Load factor variations have relevant impact, but even the worst case scenario conversion is a positive NPV deal. The same is true for WACC, NPVs vary substantially in function of WACC but are never close to negative. Sensitivity to CAPEX variations is extremely low, this results from the high ratios of NPV over CAPEX. As expected NPV decreases when the spread of the forward rates of fuel oil over natural gas approaches 0% of its current value (when curves in Figure 3 become superimposed) but NPV only becomes negative when natural gas is the same price as fuel oil, this is explained by the fact that natural gas has a better CO_2 performance than fuel oil. Financials for the upgrade of fuel oil boilers to natural gas are clear, conversion is a profitable operation with low risk of negative NPV. Low CAPEX and high spread between the price of fuel oil and natural gas are the key drivers for the deal.

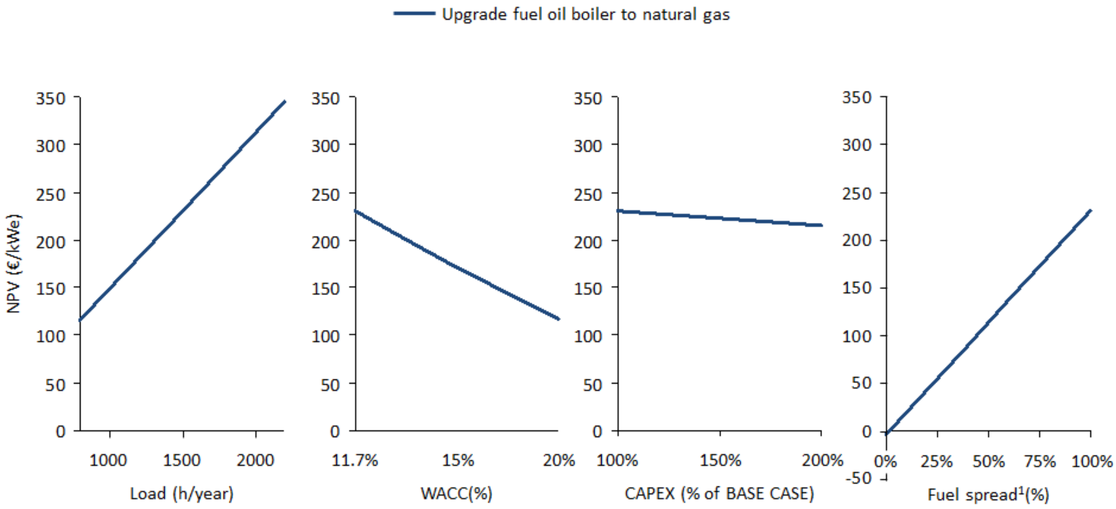

Figure 25 – Sensitivity analysis of upgrade from fuel oil boiler to natural gas boiler Base case - CAPEX: 100%, WACC: 11.7%, Load: 1500 h/year
(1)100% spread between fuel oil and natural gas is the current spread on the European forward markets (Figure 3), 0% spread was modeled by reducing the price of fuel oil until its forward curve is the same as the forward curve of natural gas

4.3.2 Economic validation of fuel oil CHP plant switch to natural gas

Load factors of Portuguese CHP facilities were obtained from the ratio between the total CHP non-renewable power production from August 2011 to July 2012, 4834 GWh (ERSE, 2012), and the total non-renewable installed CHP power capacity, 1265 MW (DGEG, see Figure 1). Average load factor in Portugal for a non-renewable CHP facility is 3821 hours per year. Load factors for steam boilers and CHP plants have different profiles, due to this fact a technology transition from boiler to CHP or *vice versa* will not be considered in this project, tough for specific cases this hypotheses should be tested.

For CHP diesel engines running on fuel oil there are four possible technology switches allowing a shift to natural gas (i) conversion of Diesel engine to Otto engine, (ii) conversion of Diesel engine to dual-fuel (running on 70% natural gas and 30% fuel oil), (iii) installation of a new CHP Otto engine and (iv) installation of new CHP natural gas turbine. The base case for CHP will use a load factor of 3800 hours/year and 11.7% WACC, as justified previously in this topic. Under these conditions we have:

Base case - WACC: 11.7%, Load: 3800 h/year			
	CAPEX (€/kWe)	**NPV (€/kWe)**	**Payback (years)**
(i) Upgrade CHP Diesel to Otto	333	1143	1.9
(ii) Upgrade CHP Diesel to dual-fuel	83	801	0.6
(iii) New CHP Otto	926	1289	5.2
(iv) New CHP Turbine	772	1437	4.3

Table 5 – CAPEX, NPV and payback for CHP Diesel engine fuel switch project

Conversions (i) and (ii) have lower CAPEX and shorter payback periods but also lower NPVs, conversely conversions (iii) and (iv) have higher CAPEX and longer payback periods but also boast higher NPVs. Conversions (i), (ii) and (iv) have a tradeoff relation between CAPEX and NPV, lower CAPEX implies lower NPVs, if low CAPEX is valued then it is hard to define a best option. Nevertheless in this context conversion (iii) is clearly inferior since it has a higher CAPEX and longer payback period but lower NPV than (iv). Common to all conversions is the fact that fuel switching from fuel oil to natural gas in CHP Diesel engine is a positive NPV deal.

Sensitivity analysis for the conversion of a CHP engine along dimensions of load factor, WACC, CAPEX and spread of fuel oil premium over natural gas follows in Figure 26. As it is clear the results obtained for the conversion of a CHP diesel engine to natural gas are quite robust. In general it is observable that conversion (i) and (ii) are less sensitive to variations in the assumptions, this effect arises from lower CAPEX involved in these two conversions. Higher load factors benefit conversions (iii) and (iv) conversely lower load benefit conversions (i) and (ii). For a load factor of 2800 hours/year, option (i) has higher NPV than option (iii) an inversion of the base case merit order. All projects are extremely sturdy to variations in WACC. Smaller WACC favors higher CAPEX conversions, higher WACC favors low CAPEX options and may alter the merit order of the base case. Conversion (i) and (ii) are not sensitive to variations in CAPEX, this results from the fact that in those cases NPVs are much larger than CAPEX. As expected NPVs approach zero when spread of the forward rates of fuel oil over natural gas tends to 0% of its current value (when curves in Figure 3 become superimposed), conversion (ii) because it uses only 70% of natural gas (30% is fuel oil) is less sensitive to this spread. Conversions (iii) and (iv) have positive NPVs even when the spread of fuel oil over natural gas is 0%, this fact results from reduced CO_2 emissions of natural gas when compared to fuel oil and from the extension of feed-in tariff period for new CHP facilities.

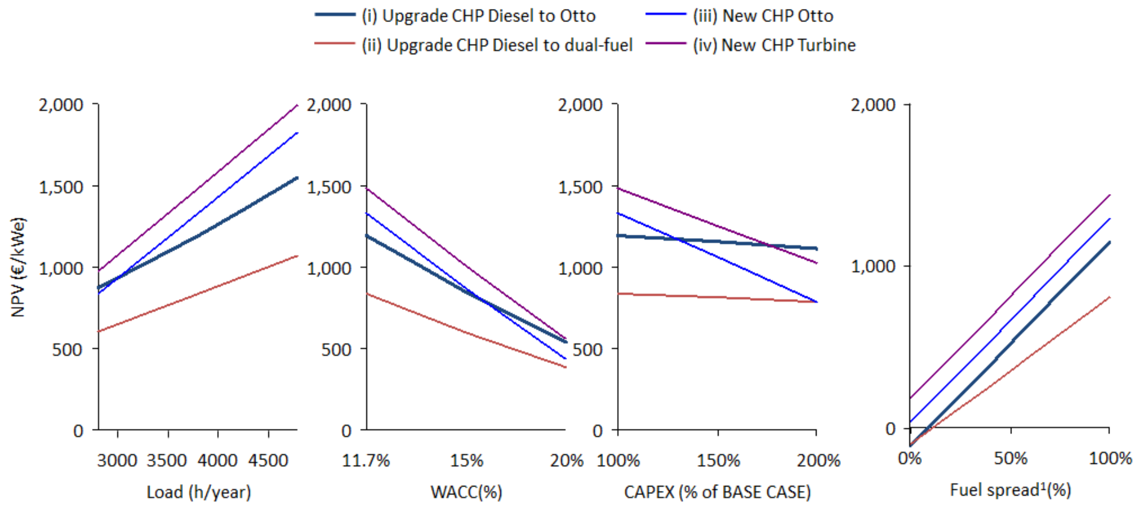

Figure 26 – Sensitivity analysis for variations in load, WACC , CAPEX and fuel spread. Base case – WACC 11.7%, load 3800 hour/year and CAPEX stated in annex 5

(1)100% spread between fuel oil and natural gas is the current spread on the European forward markets (Figure 3), 0% spread was modeled by reducing the price of fuel oil until its forward curve is the same as the forward curve of natural gas

5. Conclusions

Energy consumption in the Portuguese industry, services, agriculture and fishing [Figure 4 and Figure 5] has registered two main trends over the last decade. The first is a technology transition from separated heat and power (SHP) to combined heat and power (CHP) marked by a strong increase in CHP installed capacity [Figure 1]. The second is the increase in the consumption of natural gas accompanied by a decline in fuel oil and LPG consumption. Fuel switching from fuel oil and LPG to natural gas is explained by the cost differences between these fuels, fuel oil (66 €/MWh) and LPG (78 €/MWh) are substantially more expensive than natural gas (36 €/MWh). LPG has had, at least since 2003, a heavy and stable premium over natural gas [Figure 2]. Fuel oil also pays a premium over natural gas, since 2003, when legislation limited the utilization of fuel oil with sulfur content superior to 1%, fuel oil premium over natural gas has been steadily increasing [Figure 2]. This spread is likely to decrease slightly in the coming years but fuel oil is expected to remain an expensive alternative to natural gas[Figure 3]

Following the clues from the Portuguese energy balance it was possible to narrow down the subsectors in which the transition from LPG and fuel oil to natural gas had the greatest potential. LPG is mostly consumed in *Services*, *Food Beverages and Tobacco* and *Metal Machinery* sectors, total consumption is equivalent to a 59 million € per year natural gas market. Consumption of LPG is mostly associated with cooking, heating and burners used in the metal industry. Transition from LPG to natural gas could be limited only by the inexistence of natural gas distribution network. Fuel oil consumption in Portugal has been decreasing over the last decade, still, in 2011 the segments analyzed represented a 178 million € per year market were they to be converted to natural gas. Currently fuel oil is mostly consumed in fuel oil steam boilers and CHP Diesel engines. Steam boilers are common in the food and beverages segments in particular in the tomato concentrate, sugar refining, dairy and beer sectors. CHP Diesel engines are cross sectorial, pervasive in food, textiles, chemical and other sectors.

Financial modeling of fuel oil boiler switch to natural gas allowed to conclude that this transition has a NPV of 223 €/kWt and a 11 month payback period. Economic value of this switch is positive even under extreme stress of the underlying assumptions, the reason for such robustness results from having a CAPEX one order of magnitude smaller than the expected NPV. Boiler upgrade is a must do investment, it is even surprising to verify that such transitions did not occur earlier. Reasons for delayed switching may be attached to low load factors associated to the combustion systems used, difficulties in financing or fears that premium currently paid by fuel oil over natural gas may vanish. The fact is that none of these reasons is sufficient to explain the lack of action in the food sector. NPVs are positive even under low load factors, CAPEX is extremely low compared to NPV leading to short payback periods, and finally, international markets do not anticipate an end to the gap between fuel oil and natural gas prices[Figure 3], but even in the extreme case where this gap is completely close NPV is only slightly negative, -4 €/kWt.

Conversion of CHP Diesel engines to natural gas was also the subject of economic valuation, including the modeling of feed in tariff paid to electricity produced in CHP plants. In this case options for both an engine upgrade and the installation of a new engine were analyzed. Two versions of engine upgrade were studied, the upgrade to natural gas engine (Otto cycle) and the upgrade to a dual fuel system (Diesel cycle) using 30% fuel oil and 70% natural gas, both with positive NPVs, low CAPEX and short pay back periods. In addition, two instances for installation of completely new CHP systems were analyzed, the CHP gas turbine and the CHP Otto engine, both choices involved higher CAPEX and higher payback periods but also higher NPVs. The appropriate choice of transition depends on a variety of factors inherent to a particular case, namely, financing options, load factor, quality of heat, type of industrial process etc… Independent of any of these factors seems to be the transition itself, in any of the studied cases, under strong assumption stress, the NPV of a shift from CHP Diesel engine to a natural gas CHP system is unequivocally positive. These results are not surprising; a strong trend of CHP conversion is already underway, quite visible in the textile sector in particular, where during 2012 three CHP diesel engines were converted to natural gas and two other conversions were underway.

Final recommendations directed at natural gas suppliers and industrial project promoters are: (i) Approach large operators of tomato concentrate, dairy, beer production and sugar refining facilities in order to procure the upgrade of existing fuel oil boilers to natural gas systems. (ii) Approach facilities in which CHP diesel engines are still consuming fuel oil and promote a transition to natural gas, namely in the food, beverages, textiles and wood industry segments. (iii) Approach the operators of large facilities for the treatment of metal surfaces and fusion of nonferrous metal in order to promote a shift from LPG to natural gas.

	Fuel Oil - Boiler (ktoe)	Fuel oil - CHP (ktoe)	LPG (ktoe)	Comments
Food, beverages and tobacco	69	50	20	Excellent fuel switching potential from fuel oil to natural gas, both in CHP Diesel engines and in boilers. Tomato concentrate, dairy, beer and sugar refining are the most relevant targets
Paper & Pulp	29	30	2	In this industry fuel oil is mostly consumed in auxiliary systems or as an auxiliary fuel to start combustion of other fuels.
Textiles	8	66		Excellent fuel switching potential. Database in annex 8 indicates the existence of 7 CHP Diesel engines that could be a target for a conversion to natural gas.
Chemicals and Plastics	5	52	12	Good fuel switching potential. Database in annex 8 indicates the existence of 5 CHP Diesel engines that could be a target for fuel switching.
Wood and wood articles	-	32	2	Good fuel switching potential. Database in annex 8 indicates the existence of 3 CHP Diesel engines that could be a target for fuel switching.
Metal machinery	-	3	21	Annex 9 identifies several large LPG consumers that could be a target for a transition to natural gas, mostly in the metal surfaces treatment and nonferrous metal fusion subsectors. Switching could be limited due to lack of natural gas network
Services	28	5	48	LPG potential could be limited by lack of natural gas distribution network. Consumers are to identify and likely run small scale operations.

Table 3 – Summary of most relevant switching potential

6. Shortcomings and future research

This project was not able to appropriately characterize fuel consumption in the *services* sector. The *services* sector does not have as detailed environmental records as the industrial sector leaving no data trail to be followed. This project was able to identify a dataset reporting on installed capacity and fuel consumption of service buildings' heating and cooling systems. This database consists of the collection of RCESE (Regulamento dos Sistemas Energéticos de Climatização em Edifícios). The database is maintained by ADENE which for legal reasons was not able to share its content.

The type of analysis executed focused mainly in technologies that deliver steam or heat. This approach allowed to easily find transition between fuels used to produce heat or vapor, but it did not allow inferring the potential for electrification. Future research could help map potential value creation through electrification of the Portuguese industry.

Annex 1 – Portuguese energy balance in 2011 (ktoe)

		Separate heat and power (SHP)											Combined heat and power (CHP)								
			Oil used as energy																		
		Coal	LPG	Diesel	Fuel oil	Petroleum coke	Others	Natural gas	Biomass	Others	Electricity	Heat [1]	Fuel oil	Natural gas	Biomass	Black liquor	Other fuels	Electricity	Heat	Total [2]	% total
Manufacturing sector	**Food beverages and tobacco**	-	22	24	69	-	2	116	93	-	161	60	50	69	-	-	-	- 30	- 60	576	7%
	Textiles	-	3	-	8	-	1	110	56	-	79	38	66	85	-	-	-	- 58	- 38	350	4%
	Paper & Pulp	-	2	4	29	-	-	78	-	-	264	953	30	380	154	878	1	- 302	- 953	1518	19%
	Chemicals and plastics	12	12	2	5	-	-	128	37	-	189	200	52	214	-	-	60	- 65	- 200	646	8%
	Ceramics	-	5	3	-	13	-	244	354	6	40	22	7	42	-	-	-	- 17	- 22	697	9%
	Glass	-	1	1	-	-	-	183	-	-	39	-	-	-	-	-	-	-	-	224	3%
	Cement	3	1	19	3	362	-	31	11	67	74	-	-	2	-	-	-	- 1	-	572	7%
	Metallurgic	-	3	1	-	-	-	12	6	-	18	-	-	-	-	-	-	-	-	40	0%
	Steel mill	4	-	1	-	-	-	45	-	1	101	-	-	-	-	-	-	-	-	152	2%
	Clothing	-	3	-	1	-	1	13	-	- 1	26	3	6	5	-	-	-	- 4	- 3	50	1%
	Wood and wood articles	-	2	6	-	-	-	9	23	-	50	20	32	-	18	-	-	- 15	- 20	125	2%
	Rubber	-	-	-	-	-	-	3	-	-	17	12	-	15	-	-	2	- 4	- 12	33	0%
	Metal machinery	-	21	4	-	-	-	49	-	-	151	-	3	-	-	-	-	- 1	-	227	3%
	Other industries	-	2	21	2	-	-	13	1	-	89	3	-	-	-	-	1	- 1	- 1	130	2%
Construction		-	8	136	21	-	2	11	-	-	48	-	-	-	-	-	-	-	-	226	3%
Mining		-	2	41	1	-	-	7	-	- 1	50	37	4	77	-	-	-	- 28	- 37	153	2%
Services		-	48	81	28	-	26	214	-	10	1461	61	5	52	-	-	2	- 21	- 20	1947	24%
Agriculture and fishing		-	6	330	14	-	2	5	-	-	84	2	-	-	-	-	-	-	-	443	5%
Total		19	141	674	181	375	34	1.271	581	82	2.941	1.411	255	941	172	878	66	-547	-1.366	**8109**	
		0%	2%	8%	2%	5%	0%	16%	7%	1%	36%	17%	3%	12%	2%	11%	1%	-7%	-17%		

Source: Energy balance DGEG 2011
(1) Includes thermal solar
(2) Adds final consumption of electricity and heat to primary consumption of fuels
(3) Mostly residue gas

Annex 2 – Emission factor, oxidation factor a lower heating value (LLH) of selected fuels

Combustível	Factor de Emissão - FE (kg CO2/GJ)	Factor de Oxidação - FO	Poder Calorífico Inferior - PCI	
Gás Natural	56,1	0,995	38,46	$GJ/(Nm^3 x10^3)$
Fuelóleo	77,4	0,99	40,36	GJ/t
Gás Petróleo Liquefeito	63,1	0,995	48,55	GJ/t
Gasóleo	74,1	0,99	43,3	GJ/t
Gasolina	68,6	0,99	44,8	GJ/t
Coque Petróleo	100,8	0,99	27,0	GJ/t
Coque Carvão	102	0,98	28,0	GJ/t
Antracite	96,1	0,98	27,75	GJ/t
Carvão Betuminoso	92	0,98	25,98	GJ/t
Querosene	71,9	0,99	43,7	GJ/t
Óleo Residual	77,4	0,99	40,2	GJ/t
Óleo Reciclado	76,6	0,99	40,4	GJ/t

Source: APA – Portuguese inventory of greenhouse gas emissions (2008)

Annex 3 – Production value, gross margin, purchase of energy products and estimation of fraction of energy related costs of selected industry sectors in Portugal for 2010

NACE_R2/INDIC_SB	(a) Production value M€	(b) Gross margin on goods for resale M€	(c) Purchases of energy products (in value) M€	(d) Number of companies	Energy costs % (c/(a-b))	Production value/companie M€ (a/d)
C - Manufacturing	72.641,6	3.487,4	2.898,7	74081	4,2%	0,98
C10 - Manufacture of food products	9.836,1	905,5	374,6	9741	4,2%	1,01
C103 - Processing and preserving of fruit and vegetables	511,3	17,8	41,0	236	8,3%	2,17
C1031 - Processing and preserving of potatoes	53,5	3,2	4,6	22	9,1%	2,43
C1032 - Manufacture of fruit and vegetable juice	56,5	0,6	3,4	10	6,1%	5,65
C1039 - Other processing and preserving of fruit and vegetables	401,3	14,1	33,0	204	8,5%	1,97
C105 - Manufacture of dairy products	1.461,7	178,4	51,6	439	4,0%	3,33
C1051 - Operation of dairies and cheese making	1.413,6	177,2	49,6	391	4,0%	3,62
C1062 - Manufacture of starches and starch products	28,5	0,2	4,7	4	16,6%	7,13
C1081 - Manufacture of sugar	293,2	0,7	19,2	6	6,6%	48,87
C11 - Manufacture of beverages	2.705,2	384,6	56,7	1109	2,4%	2,44
C1105 - Manufacture of beer	698,8	255,3	16,0	9	3,6%	77,64
C13 - Manufacture of textiles	2.813,5	63,8	227,9	3539	8,3%	0,79
C16 - Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	2.529,0	151,0	119,8	6580	5,0%	0,38
C17 - Manufacture of paper and paper products	3.359,6	39,0	385,2	501	11,6%	6,71
C171 - Manufacture of pulp, paper and paperboard	2.449,1	4,1	328,2	47	13,4%	52,11
C1711 - Manufacture of pulp	1.115,0	0,0	162,2	10	14,5%	111,50
C1712 - Manufacture of paper and paperboard	1.334,2	4,1	165,9	37	12,5%	36,06
C172 - Manufacture of articles of paper and paperboard	910,5	34,9	57,0	454	6,5%	2,01
C20 - Manufacture of chemicals and chemical products	3.942,6	195,6	204,4	810	5,5%	4,87
C21 - Manufacture of basic pharmaceutical products and pharmaceutical preparations	1.053,4	223,2	26,2	138	3,2%	7,63
C23 - Manufacture of other non-metallic mineral products	4.290,6	150,2	568,6	4765	13,7%	0,90
C231 - Manufacture of glass and glass products	858,9	-44,2	128,5	487	14,2%	1,76
C2351 - Manufacture of cement	637,5	36,5	141,0	13	23,5%	49,04
C28 - Manufacture of machinery and equipment n.e.c.	1.703,3	147,4	32,8	1684	2,1%	1,01
C29 - Manufacture of motor vehicles, trailers and semi-trailers	5.948,1	51,2	74,0	529	1,3%	11,24

Sources: EUROSTAT – Industry, trade and services database

Annex 4 – CAPEX for array of CHP installation in Portugal

Investor	Technology	Fuel	Installed capacity (MW)	Investment (M€)	M€/MW	Date
STP	Diesel engine	FO	6,5	3,8	0,58	1994
STP	Diesel engine	FO	6,5	4,5	0,69	1995
STP	Diesel engine	FO	6,5	4,5	0,69	1996
STP	Diesel engine	FO	4,7	3,9	0,84	1996
STP	Diesel engine	FO	6,5	4,9	0,75	1997
STP	Diesel engine	FO	3,8	3,3	0,87	1997
STP	Diesel engine	FO	4,3	3,8	0,88	1998
STP	Diesel engine	FO	4,2	3,5	0,84	1998
Finertec		FO	3,9	4,7	1,21	1998
Finertec		FO	5,5	6,6	1,20	1995
Finertec		FO	6,5	7,8	1,20	1994
Finertec		FO	7,2	8,7	1,21	1996
STP	Natural gas engine	GN	3,9	2,5	0,64	1997
STP	Natural gas engine	GN	4,3	4,1	0,96	1997
STP	Natural gas engine	GN	5,9	3,5	0,59	1999
STP	Natural gas engine	GN	4,0	3,0	0,75	2000
STP	Natural gas engine	GN	2,7	2,0	0,73	2001
STP	Natural gas engine	GN	3,2	2,2	0,68	2005
STP	Natural gas engine	GN	3,6	2,4	0,66	2005
STP	Gas turbine	GN	7,3	5,7	0,78	2002
STP	Gas turbine	GN	30,3	33,5	1,11	2005
STP	Gas turbine	GN	5,1	4,0	0,78	2006
Finertec		GN	5,5	7,2	1,31	2002

STP: Sociedade térmica Portuguesa
Source: STP, Finertec

Annex 5 – Efficiencies, maintenance costs, and CAPEX for different technologies

	Boiler Upgrade FO to NG	CHP Diesel upgraded to NG	CHP Diesel upgraded to Dual Fuel	CHP Otto NG	CHP Turbine NG	CHP Diesel
Thermal efficiencies	90,0%	47,0%	45,0%	45,0%	45,0%	42,0%
CHP electrical efficiencies	0,0%	30,0%	29,0%	31,0%	31,0%	27,5%
Reference electrical efficiencies (to calculate PEP)	0,0%	51,0%	48,0%	51,0%	51,0%	43,0%
Reference thermal efficiencies (to calculate PEP)	0,0%	89,0%	89,0%	90,0%	90,0%	89,0%
PEP (Poupança de energia primária)		10%	10%	10%	10%	10%
Var thermal cost O&M (€'12/MWh)	1,0					
Var electrical cost O&M (€'12/MWh)		9,8	9,8	9,8	6,4	9,8
CAPEX (€'12/kWt)	xxx					
CAPEX (€'12/kWe)		333,0	83,0	926,4	771,7	1335,2

Source: (U.S. Environmental Protection Agency, 2008) (COGEN Portugal, 2011) (Antunes, 2012) (Endesa Portugal) (Finertec Energia SPGS S.A.)
xxx – EDP Energia de Portugal confidential data

Annex 6 – CHP technology characteristics

Table III: Summary Table of Typical Cost and Performance Characteristics by CHP Technology*					
Technology	**Steam Turbine[1]**	**Recip. Engine**	**Gas Turbine**	**Microturbine**	**Fuel Cell**
Power efficiency (HHV)	15-38%	22-40%	22-36%	18-27%	30-63%
Overall efficiency (HHV)	80%	70-80%	70-75%	65-75%	55-80%
Effective electrical efficiency	75%	70-80%	50-70%	50-70%	55-80%
Typical capacity (MW_e)	0.5-250	0..01-5	0.5-250	0.03-0.25	0.005-2
Typical power to heat ratio	0.1-0.3	0.5-1	0.5-2	0.4-0.7	1-2
Part-load	ok	ok	poor	ok	good
CHP Installed costs ($/kW$_e$)	430-1,100	1,100-2,200	970-1,300 (5-40 MW)	2,400-3,000	5,000-6,500
O&M costs ($/kWh$_e$)	<0.005	0.009-0.022	0.004-0.011	0.012-0.025	0.032-0.038
Availability	near 100%	92-97%	90-98%	90-98%	>95%
Hours to overhauls	>50,000	25,000-50,000	25,000-50,000	20,000-40,000	32,000-64,000
Start-up time	1 hr - 1 day	10 sec	10 min - 1 hr	60 sec	3 hrs - 2 days
Fuel pressure (psig)	n/a	1-45	100-500 (compressor)	50-80 (compressor)	0.5-45
Fuels	all	natural gas, biogas, propane, landfill gas	natural gas, biogas, propane, oil	natural gas, biogas, propane, oil	hydrogen, natural gas, propane, methanol
Noise	high	high	moderate	moderate	low
Uses for thermal output	LP-HP steam	hot water, LP steam	heat, hot water, LP-HP steam	heat, hot water, LP steam	hot water, LP-HP steam
Power Density (kW/m^2)	>100	35-50	20-500	5-70	5-20
NO_x (lb/MMBtu) (not including SCR)	Gas 0.1-.2 Wood 0.2-.5 Coal 0.3-1.2	0.013 rich burn 3-way cat. 0.17 lean burn	0.036-0.05	0.015-0.036	0.0025-.0040
lb/MWh$_{TotalOutput}$ (not including SCR)	Gas 0.4-0.8 Wood 0.9-1.4 Coal 1.2-5.0.	0.06 rich burn 3-way cat. 0.8 lean burn	0.17-0.25	0.08-0.20	0.011-0.016

* Data are illustrative values for typically available systems; All costs are in 2007$

[1]For steam turbine, not entire boiler package

Source: (U.S. Environmental Protection Agency, 2008)

Annex 7 – Energy consumption database (APA)

Indústria		Consumos energéticos (tep)				Ano da Licença Ambiental	CHP
Sector	Subsector	Gás Natural	Fuelóleo	GPL	Eletricidade		
Energia	Instalações com cogeração	90511			549	2011	S
		15882			6	2009	S
		102791			690	2006	S
		148330			1479	2006	S
		53926			444	2010	S
		48486			22	2010	S
			33915		516	2008	S
		15097			8382	2008	S
		976	6413		8169	2008	S
			7477		4283	2008	S
Produção e transformação de metais	Instalações de produção de gusa ou aço (fusão primária ou secundária), incluindo os equipamentos de vazamento contínuo com uma capacidade superior a 2,5 t por hora	4201	17173	0	35512	2008	
		43680	0	0	72657	2005	
	Instalações para o processamento de metais ferrosos por: Aplicação de revestimentos protectores d e metal em fusão com uma capacidade de tratamento superior a 2 ton. de aço bruto por hora	615	0	0	86	2008	
		828	0	0	138	2007	
		440	0	0	820	2008	
		637	0	0	155	2006	
		273	0	0	38	2012	
		27271	0	0	11	2008	
		944	0	0	208	2009	
		0	0	1067	1517	2008	
	Fundições de metais ferrosos com uma capacidade de produção superior a 20 t por dia	294	0	0	841	2009	
		0	0	16	718	2009	
		4	0	11	774	2007	
		0	0	62	310	2008	
		0	0	124	1025	2010	
		636	0	0	4738	2009	
		974	0	0	774	2007	
		0	0	0	343	2010	
		570	0	0	11085	2009	
	Instalações para a: Produção de metais brutos não ferrosos a partir de minérios, de concentrados ou de matérias -primas secundárias por processos metalúrgicos, químicos ou electrolíticos	2128	0	0	361	2009	
		0	1848	0	88	2007	
	Instalações para a: Fusão de metais não ferrosos, incluindo ligas, produtos de recuperação (afinação, moldagem em fundição) com uma capacidade de fusão superior a 4 t por dia de	272	0	2	430	2009	
		0	0	202	1256	2009	
		0	0	61	341	2008	
		0	0	781	2140	2005	
		23	0	0	843	2004	
		0	0	10	320	2009	

	chumbo e de cádmio ou a 20 t por dia de todos os outros metais	1854	0	0	1047	2008	
		0	0	16	13	2008	
		1503	0	0	651	2008	
		1767	0	0	450	2009	
		1075	0	6	628	2008	
		385	0	1	208	2011	
	Instalações de tratamento de superfície de metais e matérias plásticas que utilizem um processo electrolítico ou químico, quando o volume das cubas utilizadas nos banhos de tratamento realizado for superior a 30 m3	92	0	0	89	2008	
		0	0	45	33	2008	
		0	0	229	103	2007	
		221	0	0	118	2008	
		65	0	0	51	2008	
		47	0	0	6	2011	
		76	0	0	166	2008	
		0	0	80	344	2007	
		181	0	21	206	2008	
		1001	0	0	602	2008	
		0	0	0	19	2009	
		0	0	226	387	2008	
		0	0	38	32	2008	
		0	0	39	2	2004	
		0	0	200	124	2004	
		152	0	0	129	2008	
		3	0	0	1341	2012	
		116	0	0	180	2008	
		1055	0	0	743	2008	
		0	0	511	2273	2008	
		462	0	9	417	2011	
		0	0	97	143	2005	
		179	0	0	12	2011	
		100	0	0	158	2008	
		0	0	130	38	2008	
		344	0	0	235	2008	
		291	0	0	136	2008	
		109	0	0	56	2007	
		0	0	97	82	2009	
		63	0	339	215	2008	
		0	0	81	79	2009	
		0	0	342	1015	2005	
		0	0	25	86	2008	
		0	156	57	172	2006	
		230	0	0	249	2010	
		0	0	488	255	2008	
		0	0	845	467	2008	
		321	0	0	122	2008	
		1331	0	0	1229	2009	
		243	0	0	257	2008	
		0	0	101	131	2009	
		9543	0	0	740	2008	
		299	0	0	619	2009	
		93	0	0	42	2010	
		476	0	0	206	2004	

		88	0	0	81	2008	
		354	0	0	302	2008	
		0	0	416	328	2006	
		0	0	0	106	2009	
		0	0	2	32	2008	
		0	0	125	248	2004	
		0	0	133	118	2008	
		215	0	0	358	2005	
Indústria mineral	Instalações de produção de: Clínquer em fornos rotativos com uma capacidade de produção superior a 500 t por dia, ou noutros tipos de fornos com uma capacidade de produção superior a 50 t por dia	0	690	168	3697	2007	
		0	711	52	10926	2008	
		0	356	88	20755	2007	
		0	0	44	5890	2007	
		0	0	1	20378	2006	
		0	2221	156	17885	2008	
	Instalações de produção de: Cal em fornos rotativos ou noutro tipo de fornos, com uma capacidade de produção superior a 50 t por dia	6280	0	0	238	2008	
		0	0	0	260	2008	
		0	0	0	1290	2009	
		23000	1746	0	486	2007	
		0	0	0	14	2011	
		0	0	0	201	2008	
	Instalações de produção de vidro, incluindo as destinadas à produção de fibras de vidro, com uma capacidade de fusão superior a 20 t por dia	31000	0	89	6234	2011	
		29100	0	59	6793	2010	
		12300	0	0	1978	2008	
		34000	0	28	4041	2008	
		2013	23277	0	3192	2007	S
		25600	19	0	4666	2010	
		39000	0	3	9158	2010	
		22600	0	90	4127	2010	
	Instalações para a fusão de matérias minerais, incluindo as destinadas à produção de fibras minerais, com uma capacidade de fusão superior a 20 t por dia	191	0	0	103	2004	
		689	0	0	0	2006	
	Instalações de fabrico de produtos cerâmicos por aquecimento, nomeadamente telhas, tijolos, refractários, ladrilhos, produtos de grés ou porcelanas, com uma capacidade de produção superior a 75 t por dia, uma capacidade de forno superior a 4 m3 e uma densidade de carga enformada por forno superior a 300 kg/m3	2850	0	0	391	2009	
		2955	0	0	454	2007	S
		2253	0	0	294	2008	
		76	0	0	122	2008	
		0	483	0	258	2008	
		0	0	0	172	2008	
		1924	0	0	167	2008	
		5187	0	0	589	2007	S
		0	1243	69	176	2008	
		5180	0	0	354	2009	S
		0	245	955	261	2008	
		0	639	0	218	2008	
		0	4	0	223	2008	
		1967	0	0	175	2008	
		2977	0	0	285	2008	
		973	73	0	177	2009	
		0	0	0	88	2008	

		0	7268	0	1204	2012	
		2113	0	0	132	2005	S
		2769	0	0	357	2008	
		1053	1394	0	157	2008	
		0	899	0	195	2008	
		29	0	0	228	2008	
		0	0	9	154	2008	
		14770	0	0	1342	2008	S
		2855	0	0	370	2008	
		0	0	0	261	2008	
		1799	0	0	236	2008	
		0	677	4	180	2009	
		0	0	0	220	2008	
		1965	0	1	274	2009	
		935	0	0	2029	2009	S
		1990	0	0	272	2008	S
		6028	0	0	671	2007	S
		1372	0	0	158	2008	
		0	9	0	72	2008	
		0	965	0	224	2008	
		0	81	0	522	2008	
		0	41	0	401	2009	
		0	201	0	402	2008	
		2516	0	0	299	2009	
		0	1187	0	268	2008	
		1430	0	0	199	2011	S
		0	0	0	176	2009	
		0	25	0	57	2008	
		1713	259	0	297	2008	
Indústria química	Instalações químicas destinadas à produção de produtos químicos orgânicos de base, como: Hidrocarbonetos simples (acíclicos ou cíclicos, saturados ou insaturados, alifáticos ou aromáticos)	0	0	0	43	2008	
		0	0	7	0	2008	
		0	233964	0	28615	2008	
	Instalações químicas destinadas à produção de produtos químicos orgânicos de base, como: Hidrocarbonetos oxigenados, como álcoois, aldeídos, cetonas, ácidos carboxílicos, ésteres, acetatos, éteres, peróxidos, resinas epóxidas	50960	0	0	5503	2008	
		46	0	0	1513	2006	
		637	0	0	112	2007	

	Instalações químicas destinadas à produção de produtos químicos orgânicos de base, como: Hidrocarbonetos azotados, como aminas, amidas, compostos nitrosos, nitrados ou nitrosados, nitrilos, cianetos, isocianatos	4458	0	0	23990	2008	
	Instalações químicas destinadas à produção de produtos químicos orgânicos de base, como: Matérias plásticas de base (polímeros, fibras sintéticas, fibras à base de celulose)	1267	0	0	2752	2009	
		7280	11718	0	4199	2008	
		0	96	0	21	2009	
		25480	0	0	3955	2007	
		2652	0	0	384	2011	
		0	0	0	34	2009	
		0	0	5	3319	2008	
		182	0	0	246	2009	
		0	112	3	0	2008	
		3413	0	0	220	2006	
		0	97	0	77	2008	
		735	0	8	206	2008	
		52	0	0	194	2011	
		2512	0	0	344	2010	
	Instalações químicas destinadas à produção de produtos químicos inorgânicos de base, como: Gases, como amoníaco, cloro ou cloreto de hidrogénio, flúor e fluoreto de hidrogénio, óxidos de carbono, compostos de enxofre, óxidos de azoto, hidrogénio, dióxido de enxofre, dicloreto de carbonilo	0	0	211	6268	2007	
	Instalações químicas destinadas à produção de produtos químicos inorgânicos de base, como: Ácidos, como ácido crómico, ácido fluorídrico, ácido fosfórico, ácido nítrico, ácido clorídrico, ácido sulfúrico, óleum, ácidos sulfurados	0	0	0	1720	2009	
	Instalações químicas destinadas à produção de produtos químicos inorgânicos de base, como: Sais, como cloreto de amónio, clorato de potássio, carbonato de potássio, carbonato de sódio,	0	0	0	18	2008	
		124	0	0	262	2008	
		0	0	0	434	2009	S
		0	0	5	7	2008	
		0	1047	0	15288	2008	
		0	0	0	1480	2003	

	perboratos, nitrato de prata						
	Instalações químicas destinadas à produção de produtos químicos inorgânicos de base, como: Não metais, óxidos metálicos ou outros compostos inorgânicos, como carboneto de cálcio, silício, carboneto de silício	11940	0	684	925	2008	
		0	0	0	130	2007	
		0	0	0	120	2006	
	Instalações químicas de produção de adubos à base de fósforo, azoto ou potássio (adubos simples ou compostos)	2582	0	0	1845	2008	
		3314	0	38	1473	2008	
	Instalações que utilizem processos químicos ou biológicos, destinadas à produção de produtos farmacêuticos de base	1520	97	1	812	2008	
		769	0	0	1035	2008	
Gestão de resíduos	Instalações de eliminação de resíduos não perigosos, que realizem as operações de eliminação D8 e D9 referidas na parte A do anexo III da Portaria n.º 209/2004, de 3 de Março, com uma capacidade superior a 50 t por dia	792	0	0	4084	2007	
	Aterros de resíduos urbanos ou de outros resíduos não perigosos, com excepção dos aterros de resíduos inertes, que recebam mais 10 t por dia ou com uma capacidade total superior a 25 000 t	0	0	0	2	2008	
		0	0	0	26	2011	
		0	0	0	45	2010	
		0	0	0	3	2011	
		0	0	0	6	2007	
		0	0	0	69	2010	
		0	0	0	7	2010	
		0	0	0	84	2007	
		0	0	0	16	2010	
		0	0	0	32	2007	
		0	0	0	9	2005	
		0	0	0	172	2010	
		0	0	0	5	2008	
		0	0	0	17	2008	
		0	0	0	3	2010	
Outras actividades	Instalações industriais de fabrico de: Pasta de papel a partir de madeira ou de outras substâncias fibrosas	0	450	9	5311	2007	
		0	21345	0	13541	2009	S
		28790	0	0	31945	2009	S
		127618	8445	3	57094	2007	S
		11389	17360	0	61537	2012	S
	Instalações industriais de fabrico de: Papel e cartão com uma capacidade de produção superior a 20 t por	8689	0	0	4299	2009	
		3313	0	0	516	2008	S
		0	1173	0	294	2009	
		1820	680	2	238	2009	

	dia	0	742	0	314	2008	
		7011	0	2	2633	2009	S
		0	12000	0	2370	2005	
		0	2104	0	1121	2009	
		651	408	0	307	2010	
		2553	0	0	834	2008	
		489	865	1	502	2008	
		0	0	0	1091	2007	
		3954	0	5	1634	2007	
		10568	0	0	2191	2007	
		10568	0	0	7078	2007	S
	Instalações destinadas ao pré -tratamento (operações de lavagem, branqueamento, mercerização) ou ao tingimento de fibras ou têxteis, cuja capacidade de tratamento seja superior a 10 t por dia	3602	0	0	754	2009	
		2003	0	0	2226	2008	S
		1192	0	2	252	2008	
		0	1825	0	915	2008	
		5327	0	16	1557	2007	
		1070	0	0	463	2008	
		1917	0	17	221	2009	
		0	573	114	1027	2008	S
		6424	0	0	1507	2007	S
		4500	0	0	475	2006	S
		1980	0	0	1163	2008	
		1330	0	0	1482	2008	
		0	0	74	473	2008	S
		1518	0	0	2279	2009	S
		2220	0	0	273	2009	
		5400	5954	0	156	2006	S
		2873	0	489	453	2008	
		0	0	0	4299	2004	S
	Instalações destinadas a: Matadouros com uma capacidade de produção de carcaças superior a 50 t por dia	177	0	19	129	2012	
		0	1157	3	1054	2010	S
		0	0	91	85	2009	
		324	0	0	270	2011	
		0	0	247	300	2009	
		0	872	200	344	2006	
		0	495	119	238	2009	
		0	350	0	140	2006	
		0	0	120	129	2006	
		0	223	48	163	2006	
		0	0	111	99	2008	
		358	0	0	243	2011	
		193	0	0	333	2006	
		132	0	0	82	2008	
		0	292	134	270	2009	
		302	0	0	244	2007	
		0	1066	91	325	2011	
		0	0	363	286	2008	
		0	339	40	361	2007	
	Instalações destinadas a: Tratamento e transformação destinados ao fabrico de	191	0	0	186	2011	
		305	0	0	458	2011	
		0	2053	0	98	2011	

	produtos para a alimentação humana e ou animal, a partir de: Matérias - primas animais (com excepção do leite), com uma capacidade de produção de produto acabado superior a 75 t por dia	183	0	0	94	2008	
		0	1647	46	1032	2007	
	Instalações destinadas a: Tratamento e transformação destinados ao fabrico de produtos para a alimentação humana e ou animal, a partir de: Matérias - primas vegetais com uma capacidade de produção de produto acabado superior a 300 t por dia (valor médio trimestral)	6	0	149	42	2005	
		0	76	3	99	2008	
		0	221	0	344	2007	
		0	132	40	160	2008	
		0	0	21	49	2008	
		0	0	10	146	2009	
		0	2102	0	186	2009	
		8	0	8	1051	2008	
		0	0	1	571	2007	
		1308	0	0	1088	2011	
		0	0	72	94	2008	
		0	0	33	127	2008	
		0	7465	1	348	2008	S
		0	141	0	144	2008	
		0	2886	18	311	2006	
		0	44	0	97	2008	
		0	0	0	732	2008	
		0	0	5	745	2008	
		5310	0	0	576	2005	
		0	0	2	566	2008	
		0	0	0	113	2007	
		83	0	0	78	2008	
		126	0	0	261	2007	
		307	0	0	376	2008	
		543	0	0	664	2008	
		0	0	31	602	2010	
		0	0	0	1156	2008	
		0	0	0	34	2007	
		0	0	3	893	2008	S
		126	0	0	174	2006	
		0	0	21	4	2008	
		0	64	0	65	2007	
		0	575	0	287	2008	
		1020	0	0	614	2008	
		0	91	0	173	2008	
		0	0	0	107	2008	
		0	0	144	127	2006	
		1098	0	6	1049	2011	
		0	0	0	2	2004	
		0	212	0	1161	2007	
		0	198	0	1249	2007	
		0	0	35	75	2008	
		18	0	0	2811	2008	S
		0	3150	16	228	2007	

		0	465	0	419	2008	S
		0	159	1	142	2006	
		0	286	0	180	2008	
		3439	0	0	2545	2007	S
		670	0	32	604	2008	
		0	0	72	68	2009	
		0	8484	1	927	2008	
		4239	0	0	617	2007	
		10400	0	22	1066	2006	S
		0	3960	13	2837	2006	S
		0	10080	4	2382	2010	S
		0	976	296	275	2006	
		0	0	0	101	2008	
		0	0	51	138	2007	
	Tratamento e transformação de leite, sendo a quantidade de leite recebida superior a 200 t por dia (valor médio anual)	1080	0	0	541	2005	
		0	2538	2	593	2008	
		10400	0	0	1066	2007	S
		0	3486	74	1422	2008	
		6140	0	0	2691	2010	
		0	3589	132	920	2005	S
	Instalações de eliminação ou valorização de carcaças e resíduos de animais com uma capacidade de tratamento superior a 10 t por dia	0	547	0	228	2008	
		1638	3100	0	731	2011	
		0	556	0	391	2008	
		0	1954	5	430	2010	
		0	0	2	143	2010	
		0	689	47	147	2012	
		0	2923	0	542	2009	
		0	2360	3	253	2011	
	Instalações para a criação intensiva de aves de capoeira ou de suínos, com espaço para mais de: 40 000 aves	0	0	0	54	2012	
		0	0	0	5	2011	
		0	0	0	3	2010	
		0	0	0	3	2012	
		0	0	0	59	2009	
		0	0	0	10	2008	
		0	0	0	41	2008	
		0	0	0	23	2012	
		0	0	21	39	2009	
		0	0	0	7	2009	
		0	0	0	7	2009	
		0	0	55	2	2009	
		0	0	0	13	2008	
		0	0	0	14	2007	
		0	0	0	3	2009	
		0	0	20	3	2009	
		0	0	0	21	2011	
		0	0	0	5	2009	
		0	0	3	62	2009	
		0	0	0	7	2009	
		0	0	1	12	2008	
		0	0	0	1	2009	
		0	0	0	44	2009	

		0	0	24	9	2009	
		0	0	19	14	2007	
		0	0	0	24	2008	
		0	0	0	2	2008	
		0	0	0	6	2008	
		0	0	237	214	2012	
		0	0	0	37	2007	
		0	0	0	47	2006	
		0	0	0	4	2011	
		0	0	5	2	2009	
		0	0	0	13	2009	
		0	0	0	3	2011	
		0	0	0	3	2009	
		0	0	39	64	2009	
		0	0	667	132	2008	
		0	0	10	4	2009	
		0	0	10	3	2009	
		0	0	41	276	2009	
		0	0	78	11	2008	
		0	0	0	20	2008	
		0	0	0	18	2007	
		0	0	0	41	2007	
		0	0	19	11	2009	
		0	0	0	32	2007	
		0	0	10	7	2009	
		0	0	15	17	2008	
		0	0	0	18	2008	
		0	0	0	5	2007	
		0	0	0	17	2008	
		0	0	0	4	2007	
		0	0	0	124	2011	
		0	0	0	18	2009	
		0	0	0	41	2008	
		0	0	0	1	2007	
		0	0	69	7	2008	
		0	0	3	17	2009	
		0	0	0	31	2008	
		0	0	66	3	2003	
		0	0	0	5	2006	
		0	0	0	3	2007	
		0	0	0	3	2009	
		0	0	133	8	2004	
		0	0	54	2	2008	
		0	0	0	26	2011	
		0	0	0	46	2008	
		0	0	0	17	2008	
		0	0	0	10	2008	
		0	0	55	1	2007	
		0	0	0	23	2008	
		0	0	66	17	2008	
		0	0	0	22	2008	

		0	0	0	19	2009	
		0	0	0	7	2007	
		0	0	94	32	2008	
		0	2923	0	542	2009	
		0	0	0	28	2009	
		0	0	0	15	2008	
		0	0	0	31	2009	
		0	0	0	25	2006	
		0	0	0	106	2008	
		0	0	0	55	2006	
	Instalações para a criação intensiva de aves de capoeira ou de suínos, com espaço para mais de: 2000 porcos de produção (de mais de 30 kg)	0	0	0	5	2011	
		0	0	0	17	2010	
		0	0	0	6	2008	
		0	0	0	21	2008	
		0	0	0	8	2009	
		0	0	0	38	2008	
		0	0	21	137	2007	
		0	0	0	23	2007	
		0	0	0	95	2003	
		0	0	0	4	2008	
		0	0	0	24	2008	
		0	0	0	18	2009	
		0	0	0	8	2007	
		0	0	0	17	2009	
		0	0	0	20	2009	
		0	0	0	28	2008	
		0	0	0	28	2006	
		0	0	0	16	2010	
		0	0	0	10	2008	
		0	0	0	3	2008	
		0	0	0	31	2008	
		0	0	0	28	2007	
		0	0	0	39	2008	
		0	0	0	11	2008	
		0	0	0	34	2008	
		0	0	0	27	2010	
	Instalações para a criação intensiva de aves de capoeira ou de suínos, com espaço para mais de: 750 porcas reprodutoras	0	0	0	34	2008	
		0	0	0	20	2006	
		0	0	0	26	2008	
		0	0	0	8	2005	
		0	0	0	33	2008	
		0	0	0	28	2006	
		0	0	0	29	2008	
	Instalações de tratamento de superfície de matérias, objectos ou produtos, que utilizem solventes orgânicos, nomeadamente para operações de apresto, impressão, revestimento, desengorduramento,	495	0	0	448	2010	
		0	0	370	140	2010	
		309	0	0	249	2008	
		0	448	0	367	2006	
		117	0	0	137	2009	
		1881	0	19	1818	2011	S
		1082	0	38	543	2008	
		1226	0	3	413	2009	

	impermeabilização, colagem, pintura, limpeza ou impregnação, com uma capacidade de consumo superior a 150 kg de solventes por hora ou a 200 t por ano	364	0	3	1151	2010	
		1	0	8	1531	2009	
		0	0	368	175	2009	
		0	0	369	745	2008	
		328	0	0	516	2008	
		0	0	288	98	2009	
		2366	0	28	1806	2007	
		0	0	374	3187	2007	
		444	0	0	195	2010	
		3565	0	0	1147	2007	
		19	0	0	681	2007	
		154	0	6	6019	2007	
		1295	0	1	468	2006	

Annex 8 – Summary of CHP database provided by COGEN Portugal

DISTRITO	SECTOR ACTIVIDADE	DATA ARRANQUE	POT. GLOBAL [MWe]	Tipo	Combustível	Notas
PORTO	ALIMENTAR	1997	3,88	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
LISBOA	ALIMENTAR	1998	3,88	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
SETÚBAL	ALIMENTAR	1998	4,30	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
AVEIRO	ALIMENTAR	1998	3,88	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
LISBOA	ALIMENTAR	2000	8,15	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
SETÚBAL	Alimentar	2007	2,80	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
SETÚBAL	ALIMENTAR	2002	7,70	Centrais a Gás Natural - Turbinas	Gás Natural	
LISBOA	ALIMENTAR	2004	7,20	Centrais a Gás Natural - Turbinas	Gás Natural	
FUNCHAL	ALIMENTAR	1992	0,39	Centrais a Gás Propano	Gás propano	
LISBOA	Alimentar	1937	1,24	Centrais de Cogeração a Contrapressão - Fuel óleo	Fuelóleo	
LISBOA	Alimentar	1984	0,60	Centrais de Cogeração a Contrapressão - Fuel óleo	Fuelóleo	
PORTO	Alimentar	1989	4,00	Centrais de Cogeração a Contrapressão - Fuel óleo	Fuelóleo	
LISBOA	ALIMENTAR	1994	4,60	Centrais de Cogeração Diesel	Fuelóleo	
LISBOA	ALIMENTAR	1996	3,40	Centrais de Cogeração Diesel	Fuelóleo	
AVEIRO	ALIMENTAR	1996	8,29	Centrais de Cogeração Diesel	Fuelóleo	
SETÚBAL	ALIMENTAR	1997	6,51	Centrais de Cogeração Diesel	Fuelóleo	
SANTARÉM	ALIMENTAR	1997	3,82	Centrais de Cogeração Diesel	Fuelóleo	
SANTARÉM	ALIMENTAR	1998	3,82	Centrais de Cogeração Diesel	Fuelóleo	
AVEIRO	CERÂMICA	1998	1,03	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
LISBOA	CERÂMICA	1998	3,88	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
LEIRIA	CERÂMICA	2000	1,03	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
AVEIRO	CERÂMICA	2000	1,03	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
AVEIRO	Cerâmica	2001	1,00	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
AVEIRO	Cerâmica	2004	1,20	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
SANTARÉM	Cerâmica	2007	1,30	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
AVEIRO	CERÂMICA	2011	1,39	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
COIMBRA	CERÂMICA	2011	1,36	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
AVEIRO	CERÂMICA	2000	3,50	Centrais a Gás Natural - Turbinas	Gás Natural	
LEIRIA	CERÂMICA	2001	3,89	Centrais a Gás Natural - Turbinas	Gás Natural	
LEIRIA	CERÂMICA	2001	3,89	Centrais a Gás Natural - Turbinas	Gás Natural	
LEIRIA	Cerâmica	2004	5,00	Centrais a Gás Natural - Turbinas	Gás Natural	
LISBOA	CERÂMICA	1994	5,63	Centrais de Cogeração Diesel	Fuelóleo	
AVEIRO	CERÂMICA	1997	4,20	Centrais de Cogeração Diesel	Fuelóleo	
V. CASTELO	CERÂMICA	1997	4,27	Centrais de Cogeração Diesel	Fuelóleo	
SETÚBAL	CORTIÇA	1998	4,17	Centrais de Cogeração Diesel	Fuelóleo	
PORTO	CORTUMES	1992	4,40	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	Convertido para GN
SETÚBAL	EMBALAGENS	1993	5,54	Centrais a Gás Propano	Gás propano	
AVEIRO	EMBALAGENS	1994	4,24	Centrais de Cogeração Diesel	Fuelóleo	
PORTO	ETAR	1991	0,46	Centrais a Biogás	Biogás	
VISEU	ETAR	1992	0,14	Centrais a Biogás	Biogás	
AVEIRO	ETAR	1993	0,21	Centrais a Biogás	Biogás	
SANTARÉM	ETAR	1993	0,13	Centrais a Biogás	Biogás	
BRAGA	ETAR	1993	0,46	Centrais a Biogás	Biogás	

LISBOA	ETAR	1998	1,45	Centrais a Biogás	Biogás	
LEIRIA	ETAR	2000	0,15	Centrais a Biogás	Biogás	
0	ETAR	1999	0,28	Centrais a Biogás	Biogás	
Abrantes	ETAR	2002	0,12	Centrais a Biogás	Biogás	
Bragança	ETAR	2004	0,17	Centrais a Biogás	Biogás	
Espinho	ETAR	2005	0,76	Centrais a Biogás	Biogás	
Sesimbra	ETAR	2006	0,12	Centrais a Biogás	Biogás	
PORTO	ETAR	2009	7,40	Centrais a Gás Natural - Turbinas	Gás Natural	
Vila Nova de Gaia	ETAR da Madalena	2003	0,47	Centrais a Biogás	Biogás	
Lisboa	ETAR de Beirolas	2001	0,32	Centrais a Biogás	Biogás	
PORTO	HOSPITALAR	2001	2,04	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
SETÚBAL	HOSPITALAR	2002	2,04	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
LISBOA	Hospitalar	2006	1,50	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
VILA REAL	HOSPITALAR	1995	0,19	Centrais a Gás Propano	Gás propano	
PORTO	MADEIRA		5,30	Centrais a Gás Natural - Turbinas	Gás Natural	
AVEIRO	Madeira	1996	0,20	Centrais de Cogeração a Biomassa	Biomassa	
VISEU	Madeira	1989	3,20	Centrais de Cogeração a Biomassa	Biomassa	
CASTELO BRANCO	Madeira	1998	0,90	Centrais de Cogeração a Contrapressão - Fuel óleo	Fuelóleo	
PORTO	MADEIRA	1994	5,58	Centrais de Cogeração Diesel	Fuelóleo	
PORTO	MADEIRA	1999	11,15	Centrais de Cogeração Diesel	Fuelóleo	
VISEU	MADEIRA	1994	13,02	Centrais de Cogeração Diesel	Fuelóleo	
AVEIRO	METALOMECÂNICA	1998	1,46	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
BRAGA	OUTRAS	2006	5,20	Centrais a Gás Natural - Turbinas	Gás Natural	
BEJA	OUTRAS	2009	4,00	Centrais a Gás Natural - Turbinas	Gás Natural	
SETÚBAL	OUTRAS	2009	32,00	Centrais a Gás Natural - Turbinas	Gás Natural	
PORTO	Outras	1983	0,20	Centrais de Cogeração a Contrapressão - Fuel óleo	Fuelóleo	
AVEIRO	outras	1997	0,20	Centrais de Cogeração a Contrapressão - Fuel óleo	Fuelóleo	
AVEIRO	Outras	1998	0,30	Centrais de Cogeração a Contrapressão - Fuel óleo	Fuelóleo	
AVEIRO	PAPEL	1998	5,90	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
SANTARÉM	PAPEL	2000	5,43	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
LISBOA	PAPEL	2000	2,72	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
COIMBRA	PAPEL	2000	50,00	Centrais a Gás Natural - Turbinas	Gás Natural	
VIANA DO CASTELO	PAPEL	2005	30,00	Centrais a Gás Natural - Turbinas	Gás Natural	
LEIRIA	Papel	2004	0,95	Centrais a Gás Natural - Turbinas	Gás Natural	
SANTARÉM	Papel	2008	7,20	Centrais a Gás Natural - Turbinas	Gás Natural	
LEIRIA	Papel	2008	1,00	Centrais a Gás Natural - Turbinas	Gás Natural	
SETUBAL	Papel	2009	81,00	Centrais a Gás Natural - Turbinas	Gás Natural	
AVEIRO	Papel	1952	63,05	Centrais de Cogeração a Biomassa	Biomassa	
SANTAREM	Papel	1964	14,92	Centrais de Cogeração a Biomassa	Biomassa	
COIMBRA	Papel	1967	48,93	Centrais de Cogeração a Biomassa	Biomassa	
SETUBAL	Papel	1967	9,97	Centrais de Cogeração a Biomassa	Biomassa	
SETUBAL	Papel	1970	40,59	Centrais de Cogeração a Biomassa	Biomassa	
C.BRANCO	Papel	1970	11,05	Centrais de Cogeração a Biomassa	Biomassa	
COIMBRA	Papel	1997	0,30	Centrais de Cogeração a Biomassa	Biomassa	
V.CASTELO	Papel	1973	20,00	Centrais de Cogeração a Biomassa	Biomassa	
COIMBRA	Papel	1985	32,00	Centrais de Cogeração a Biomassa	Biomassa	
LISBOA	Papel	1967	4,70	Centrais de Cogeração a Contrapressão - Fuel óleo	Fuelóleo	

AVEIRO	Papel	1985	0,26	Centrais de Cogeração a Contrapressão - Fuel óleo	Fuelóleo	
AVEIRO	PAPEL	1996	5,23	Centrais de Cogeração Diesel	Fuelóleo	
AVEIRO	Plásticos	2011	2,00	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
LEIRIA	QUÍMICA	2001	30,00	Centrais a Gás Natural - Turbinas	Gás Natural	
LISBOA	QUÍMICA	2001	42,20	Centrais a Gás Natural - Turbinas	Gás Natural	
LISBOA	QUÍMICA	1975	8,16	Centrais a Gás Natural - Turbinas	Gás Natural	
PORTALEGRE	QUÍMICA	2005	7,00	Centrais a Gás Natural - Turbinas	Gás Natural	
PORTO	Química	2012	80,00	Centrais a Gás Natural - Turbinas	Gás Natural	
PORTO	Química	1969	23,00	Centrais a Gás Natural - Turbinas	Gás Natural	
SETUBAL	Química	2008	80,00	Centrais a Gás Natural - Turbinas	Gás Natural	
SETUBAL	Química	1978	48,00	Centrais a Gás Natural - Turbinas	Gás Natural	
SETUBAL	Química	1979	37,77	Centrais de Cogeração a Contrapressão - Fuel óleo	Fuelóleo	
SETUBAL	Química	1978	16,00	Centrais de Cogeração a Contrapressão - Fuel óleo	Fuelóleo	
AVEIRO	Química	1999	1,44	Centrais de Cogeração a Contrapressão - Fuel óleo	Fuelóleo	
AVEIRO	QUÍMICA	1994	6,52	Centrais de Cogeração Diesel	Fuelóleo	
AVEIRO	QUÍMICA	1994	5,65	Centrais de Cogeração Diesel	Fuelóleo	
SANTARÉM	serviços	1999	0,08	Centrais a Biogás	Biogás	
LISBOA	Serviços	1996	2,14	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
LISBOA	SERVIÇOS	1998	1,00	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
PORTO	SERVIÇOS	1998	5,90	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
PORTO	SERVIÇOS	1998	2,60	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
LISBOA	SERVIÇOS	1999	0,77	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
AVEIRO	SERVIÇOS	2000	2,60	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
LISBOA	SERVIÇOS	1997	5,00	Centrais a Gás Natural - Turbinas	Gás Natural	
FUNCHAL	SERVIÇOS	1992	0,13	Centrais a Gás Propano	Gás propano	
FUNCHAL	SERVIÇOS	1992	0,19	Centrais a Gás Propano	Gás propano	
FUNCHAL	SERVIÇOS	1993	0,58	Centrais a Gás Propano	Gás propano	
SANTARÉM	SERVIÇOS	1993	0,76	Centrais a Gás Propano	Gás propano	
LISBOA	SERVIÇOS	1994	0,00	Centrais a Gás Propano	Gás propano	
PORTO	SERVIÇOS	1997	5,78	Centrais de Cogeração Diesel	Fuelóleo	
PORTO	TÊXTIL	1999	5,43	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
PORTO	TÊXTIL	1999	1,40	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
BRAGA	TÊXTIL	2000	4,00	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
BRAGA	TÊXTIL	2000	2,80	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
PORTO	TÊXTIL	2000	1,36	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
PORTO	TÊXTIL	2000	2,04	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
BRAGA	TÊXTIL	2000	1,03	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
BRAGA	TÊXTIL	2000	1,03	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
BRAGA	TÊXTIL	2000	1,03	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
BRAGA	TÊXTIL	2001	5,40	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
BRAGA	TÊXTIL	2001	2,72	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
BRAGA	TÊXTIL	2002	2,04	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
AVEIRO	TÊXTIL	2002	2,72	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
BRAGA	TÊXTIL	2002	2,72	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
BRAGA	TÊXTIL	2003	1,36	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
BRAGA	TÊXTIL	2003	1,36	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
BRAGA	TÊXTIL	2003	1,36	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
PORTO	TÊXTIL	2003	2,72	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
PORTO	TÊXTIL	2003	1,36	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	

BRAGA	TÊXTIL	2004	2,19	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
PORTO	TÊXTIL	2004	1,02	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
BRAGA	TÊXTIL	2004	1,36	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
BRAGA	TÊXTIL	2004	2,72	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
PORTO	TÊXTIL	2005	2,72	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
BRAGA	TÊXTIL	2005	3,64	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
BRAGA	TÊXTIL	2005	3,22	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
PORTO	Têxtil	2007	2,70	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
BRAGA	Têxtil	2008	2,40	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
BRAGA	Têxtil	2008	3,20	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	
BRAGA	TÊXTIL	1993	8,80	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	Conversão para GN em 2012
BRAGA	TÊXTIL	1996	4,40	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	Conversão para GN em 2012
BRAGA	TÊXTIL	1993	8,60	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	Conversão para GN em 2012
BRAGA	TÊXTIL	1994	8,80	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	Convertido para GN
BRAGA	TÊXTIL	1996	4,40	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	Convertido para GN
BRAGA	TÊXTIL	1996	10,70	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	Convertido para GN
BRAGA	TÊXTIL	1995	4,40	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	Em Conversão para GN
BRAGA	TÊXTIL	1995	4,40	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	Em Conversão para GN
BRAGA	TÊXTIL	1996	4,40	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	Convertido para GN
BRAGA	TÊXTIL	1994	4,40	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	Convertido para GN
BRAGA	TÊXTIL	1993	4,30	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	Convertido para GN
BRAGA	TÊXTIL	1994	4,34	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	Convertido para GN
BRAGA	TÊXTIL	1995	4,34	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	Convertido para GN
COVILHÃ	TÊXTIL	1996	3,96	Centrais a Gás Natural - Motores Ciclo Otto	Gás Natural	Convertido para GN em 2008
PORTALEGRE	TÊXTIL	1998	7,00	Centrais a Gás Natural - Turbinas	Gás Natural	
BRAGA	TÊXTIL	2000	5,00	Centrais a Gás Natural - Turbinas	Gás Natural	
PORTO	Têxtil	1989	0,10	Centrais de Cogeração a Contrapressão - Fuel óleo	Fuelóleo	
PORTO	TÊXTIL	1994	4,24	Centrais de Cogeração Diesel	Fuelóleo	
BRAGA	TÊXTIL	1994	6,51	Centrais de Cogeração Diesel	Fuelóleo	
PORTO	TÊXTIL	1995	4,18	Centrais de Cogeração Diesel	Fuelóleo	
BRAGA	TÊXTIL	1996	6,51	Centrais de Cogeração Diesel	Fuelóleo	
BRAGA	TÊXTIL	1996	4,24	Centrais de Cogeração Diesel	Fuelóleo	
BRAGA	TÊXTIL	1997	5,53	Centrais de Cogeração Diesel	Fuelóleo	
BRAGA	TÊXTIL	1998	3,82	Centrais de Cogeração Diesel	Fuelóleo	

Annex 9 – Metal companies natural gas, LPG and electricity consumption in 2008

	Natural gas (ktoe)	LPG (ktoe)	Electricity (ktoe)
Steel production	4201	0	35512
	43680	0	72657
Ferrous metal processing	615	0	86
	828	0	138
	440	0	820
	637	0	155
	273	0	38
	27271	0	11
	944	0	208
	0	1067	1517
Ferrous metal fusion	294	0	841
	0	16	718
	4	11	774
	0	62	310
	0	124	1025
	636	0	4738
	974	0	774
	0	0	343
	570	0	11085
Nonferrous metal processing	2128	0	361
	0	0	88
Nonferrous metal fusion	272	2	430
	0	202	1256
	0	61	341
	0	781	2140
	23	0	843
	0	10	320
	1854	0	1047
	0	16	13
	1503	0	651
	1767	0	450
	1075	6	628
	385	1	208
Metal surfaces and plastics	92	0	89
	0	45	33
	0	229	103
	221	0	118
	65	0	51
	47	0	6
	76	0	166
	0	80	344
	181	21	206
	1001	0	602
	0	0	19
	0	226	387
	0	38	32
	0	39	2

	0	200	124
	152	0	129
	3	0	1341
	116	0	180
	1055	0	743
	0	511	2273
	462	9	417
	0	97	143
	179	0	12
	100	0	158
	0	130	38
	344	0	235
	291	0	136
	109	0	56
	0	97	82
	63	339	215
	0	81	79
	0	342	1015
	0	25	86
	0	57	172
	230	0	249
	0	488	255
	0	845	467
	321	0	122
	1331	0	1229
	243	0	257
	0	101	131
	9543	0	740
	299	0	619
	93	0	42
	476	0	206
	88	0	81
	354	0	302
	0	416	328
	0	0	106
	0	2	32
	0	125	248
	0	133	118
	215	0	358

Source: APA – Environmental licenses

** See section* 3.1.3

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